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THE COST OF SMALL SURFACE WATER SUPPLIES IN NEW ENGLAND

BY GEORGE A. SAMPSON*

[*Read September 14, 1938.*]

General Considerations. One of the principal factors affecting cost is the year of construction. In general, waterworks built prior to 1916 may be said to cost half as much as those constructed since that date. Although wage rates and prices of materials fluctuated from year to year during these two periods, the year 1916 may be considered to mark the dividing line between low and high costs. This cost trend is well illustrated by the price per net ton of 6-in. and larger cast-iron, bell and spigot, pit-cast, water pipe, f.o.b. Delaware River foundries, as given in the June 30, 1938, issue of the *Engineering News-Record* and shown in Figure 1. In this diagram, prices prior to 1901 are for all classes of pipe, while subsequent prices are for Class B, or heavier (American Water Works Association Specifications). Since the cost of the supply main and distribution mains represents the major portion of the total cost of a waterworks system, and because other costs have a somewhat similar trend, it may be assumed that the diagram is a fairly accurate index of the variation in the yearly cost of water supply systems.

As the purpose of this paper is to present a general method of estimating the cost of small surface water supplies, it seems preferable to relate costs to present-day prices with which we are all familiar and to apply a factor for any other year. Again, it seems better to present costs based on average conditions rather than to report the actual construction costs of various waterworks systems.

The year 1937 is assumed to be 100 in the cost index, and previous years are given percentage factors.

The mains are assumed to be cast-iron, bell and spigot, bitumastic-lined, centrifugally-cast water pipe, Class 150, Federal specifications W.W.P. 421, jointed with a lead substitute compound and ½-in. square braided yarn. The reason for this selection of pipe is to establish some basis of cost and because it is probable that other

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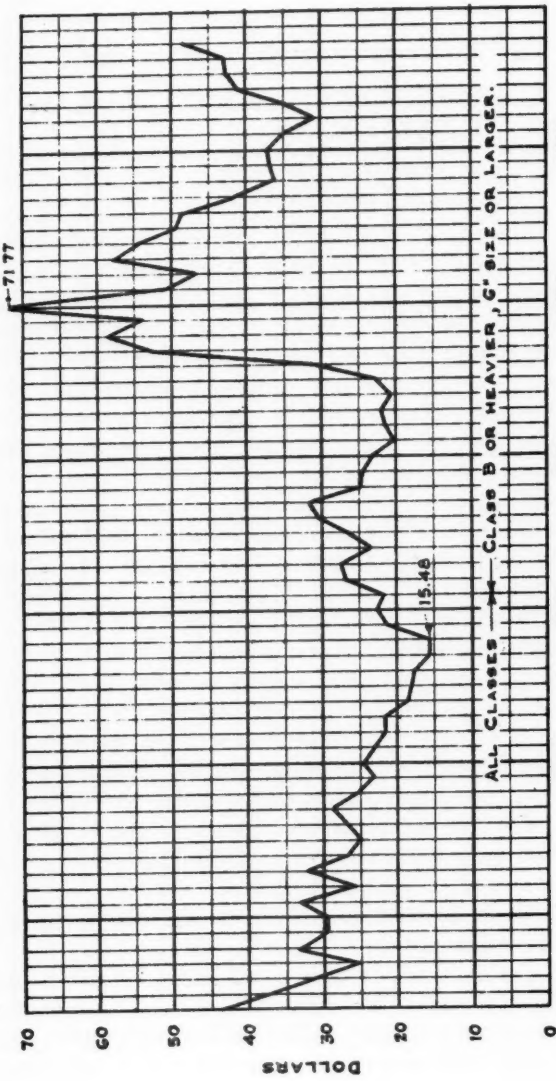
DOLLARS
70
60
50
40
30
20
10
0
1874
1880
1890
1900
1910
1920
1930
YEAR
71.77
15.46
ALL CLASSES
CLASS B OR HEAVIER, 6" SIZE OR LARGER.
COST OF BELL AND SPIGOT PIT CAST IRON PIPE
PER NET TON F.O.B. DELAWARE RIVER FOUNDRIES.
(FROM ENGR.-NEWS RECORD JUNE 30, 1938)

FIG. 1

kinds of pipe and methods of jointing would show about the same results.

The water systems are assumed to be built by contract after receiving competitive bids from competent and experienced contractors.

Parts of a Surface Supply

There are several items that must be considered in estimating the cost of a surface water supply. The principal factors are as follows:

(1) *Source of Supply.* Suitable sources may be obtained from lakes or ponds, artificial storage reservoirs, rivers, brooks, and springs, although the latter is surface ground water.

(2) *Protection of Source.* General protection of the sanitary quality of the supply is usually obtained by acquiring the properties around the lake, pond or reservoir, and by purchasing land on the watershed. In the case of large lakes, the protected area is sometimes limited to a reasonable distance from the intake. Improvement of a source by stripping reservoir sites, drainage of swamps, and forestation are cost factors. The usual legal restrictions as to bathing, boating and fishing are a further safeguard without added expense.

(3) *Treatment of Source.* With the exception of some natural lakes, ponds and springs that may supply small communities, surface water supplies usually demand some degree of treatment. Most surface sources should be chlorinated, except where adequately filtered, to guard against the hazard of water-borne diseases. Filtration of surface supplies is usually desirable to produce a good wholesome water. The type of filter, slow or rapid, with or without chemical treatment, to remove bacteria, color, turbidity, taste, odor, and microscopic organisms, is a cost item. Ordinarily, the removal of iron and corrosion correction are not necessary for surface waters.

(4) *Methods of Supply.* The simplest and least expensive supply to construct and maintain is a gravity source furnishing adequate pressures throughout the distribution system. Often, however, sufficient head cannot be obtained from any available gravity source and it is necessary to pump the water into a distributing reservoir, standpipe or elevated tank. The cost of constructing and operating the pumping plant will vary with the type of pumping units, pumping heads and other local conditions. Whether by gravity or pumping, a recording meter should be provided for determining the amount of water delivered into the distribution system.

(5) *Secondary Storage.* It is seldom that the source is of sufficient elevation and at the same time near enough to the center

FIG. 1

of distribution so that secondary storage is not advantageous. Even though the head were adequate, a smaller supply main feeding into a distributing reservoir, standpipe or elevated tank might afford better fire protection, at a saving in construction cost, as compared with a larger supply main and no secondary storage. The comparison is influenced by the length of the supply main and the site available for storage. Storage is usually provided in covered concrete reservoirs, steel standpipes and elevated steel tanks at somewhat varying costs for the same capacity.

(6) *Supply Main.* The relative cost of the supply main leading from the source to the distribution system is mostly dependent upon its length. Although its actual construction cost varies with the size, the unit cost based on the population served, or number of services, is fairly constant for different water supply systems. There is an exception, however, in small communities where possibly a minimum size of 12-in. is installed for fire protection and future growth. The same size of main would service a considerably larger population.

(7) *Distribution System.* Although there is some variance in the unit cost of distribution systems due to the average size of mains, depth of trench, amount of rock excavation, number of river and railroad crossings, pavements to be removed and replaced, interference of sewer mains, gas mains and other public utilities, number of fire hydrants, length of services and other details, the percentage of cost of the distribution system to the complete water supply can be estimated with reasonable accuracy.

(8) *Miscellaneous Costs.* In addition to the ordinary construction costs, there are usually some miscellaneous expenses that must be reckoned with, such as compensation for diversion of water, payments for land and rights-of-way, unusual difficulties in construction, booster stations to serve high-elevation districts; and other considerations. These elements may be allowed for without much difficulty when the facts are known.

Determination of Cost

Having taken into account some of the variants that may influence the cost of a surface water supply system, the author will endeavor to formulate a method of estimating construction costs and, finally, to present figures that may be used for approximate estimates.

In order to arrive at any satisfactory results, the costs must be related to some common unit of measure. This unit could be the per capita cost based on the population served, the cost per service,

or the cost per million gallons daily capacity. After applying these three standards of comparison to the actual present day costs of a number of surface supplies, it seems that the per-capita-served unit is the most accurate basis for determining the total cost of a surface water supply, and this unit has been adopted.

It is apparent that the cost of the source, protection of the source, treatment of the water, method of supply and secondary storage requirements will vary greatly with each individual system. A study of twelve surface supplies shows that the probable average cost of these items is $23 per-capita-served with water, ranging from $10 to $60, with eight of the twelve from $15 to $30.

The distribution system, however, which usually represents from 60 to 90%, and averages from 65 to 75%, of the total cost of the water system, can be determined with reasonable accuracy. The average miles of pipe, 4-in. and larger, including the supply main and force main, are as follows. The 4-in. size of pipe in the systems considered, which represents 9⅔% of the total mileage, would not be installed in a system constructed at the present time.

Population Served	Miles of Mains
1,000	6
2,000	11
4,000	21
6,000	30
8,000	39
10,000	47
12,000	55
14,000	62
16,000	69
18,000	76

There is a marked similarity in the weighted average size of mains 4-in. and larger, the mean for about twenty communities ranging in population from 500 to 17,000 being 7¼-in., and varying only from 6⅔-in. for systems which are rather economically designed to 9⅓-in. for those of liberal design and allowance for future growth.

The cost of these average sized mains installed at present prices is $1.93 per lineal foot. Many of you can remember when $1.00 per foot was considered as a good average estimate for the cast-iron mains in a distribution system. By substituting 6-in. pipe for all 4-in. pipe, the average cost per foot would be $1.96.

The unit costs for different sizes assumed in computing the average cost are listed below:

Size of Pipe (Inches)	Cost per Foot (Laid)
30	$10.90
24	7.70
20	5.87
18	5.09
16	4.31
14	3.60
12	3.04
10	2.48
8	1.98
6	1.56
4	1.23

The cost of cast-iron, bitumastic-lined specials on mains equals about 3½% of the cost of the pipe delivered, f.o.b. cars, and adds 4½¢ per lineal foot of mains, with a range of from 2½¢ to 6½¢.

Rock excavation is problematical and subject to wide variation but averages about 150 cu. yd. per mile of main, or 15¢ per lineal foot, for a complete water system in New England.

Gate valves and valve boxes installed in mains add approximately 6% to the cost of the pipe, or 8¢ per lineal foot, varying from 4¢ to 14¢.

The cost of hydrants and 6-in. connections to the mains, including gate valves, averages 13½% of the cost of the pipe for thirty-two systems, or 17½¢ per lineal foot. The range is from 11½¢ to 26½¢.

The total cost per lineal foot of mains, 4-in. and larger, including the supply and force mains, special castings, rock excavation, gate valves and hydrants, from these figures, averages $2.38, or $12,500 per mile of mains for an approximate estimate. The price may vary from $11,000 to $14,000 or more for unusual conditions. These special cases can, however, be taken into account in making an estimate.

Any wrought iron or other small mains installed in the system should be estimated separately from the 4-in. and larger mains. The average cost of 1- to 3-in. galvanized, wrought-iron mains, installed with fittings and gate valves, at present prices would be about $1.00 per lineal foot.

There is a considerable option in the kind of pipe used for services, the selection depending upon the corrosiveness of the water, character of the ground, experience of nearby communities and other influences. The division of the cost of the services between the owner and the customer also shows a wide variation. If we assume a service of non-corrosive pipe with corporation cock, lead goose neck, curb cock and service box, of good quality, with an average service length of 30 ft., to be installed by the water department, the average cost

without an allowance for pavement will be about $38 per service. If the services for any reason are longer or shorter, the difference in cost can be estimated.

The average number of persons served per service in residential communities is 4.3, with a range of from 3.5 to 4.9. The per capita cost for services from the main to the property line is, therefore, about $9. The service pipes from the property line to the houses are assumed to be installed at the expense of the customer and vary considerably in length and resulting cost. If meters are installed on services by and at the expense of the water department, in the basements of the houses, about $13 should be added per service, or $3.00 per capita. Larger services and meters for public buildings, industrial plants and other considerable users of water, can be estimated separately from those of domestic consumers.

The removal and replacement of permanent street pavements and paved sidewalks for mains and services will increase the construction cost from $0.50 to $1.50 per lineal foot of pavement, depending on the type of pavement, length, and width removed.

If there are any river crossings, railroad crossings, tunnels or other special construction, an allowance can be made to cover these items, which usually represent a small proportion of the total cost.

Finally, when the construction cost has been determined, about 15% should be added for preliminary expenses, legal services, interest during construction, engineering, general expenses, tools, equipment, and contingencies.

Estimated Cost

The writer has computed the probable 1937 cost of surface water supply systems for varying populations served with water, and submits Figures 2 and 3 as providing convenient and reasonably accurate estimates of the cost of surface supplies. Figure 2 shows the per-capita-served cost, and Figure 3 the total cost.

Three lines are shown on the diagrams. The middle line represents the average cost of such systems completely installed; the upper line, the cost under very favorable conditions; and the lower line, the cost where unusual difficulties are encountered.

Also plotted on Figure 2, and represented by circles, are the actual costs of a number of surface supplies reduced to 1937 prices. The results seem to indicate that the diagram has some foundation in fact.

For any other year previous to 1937, the costs given in the

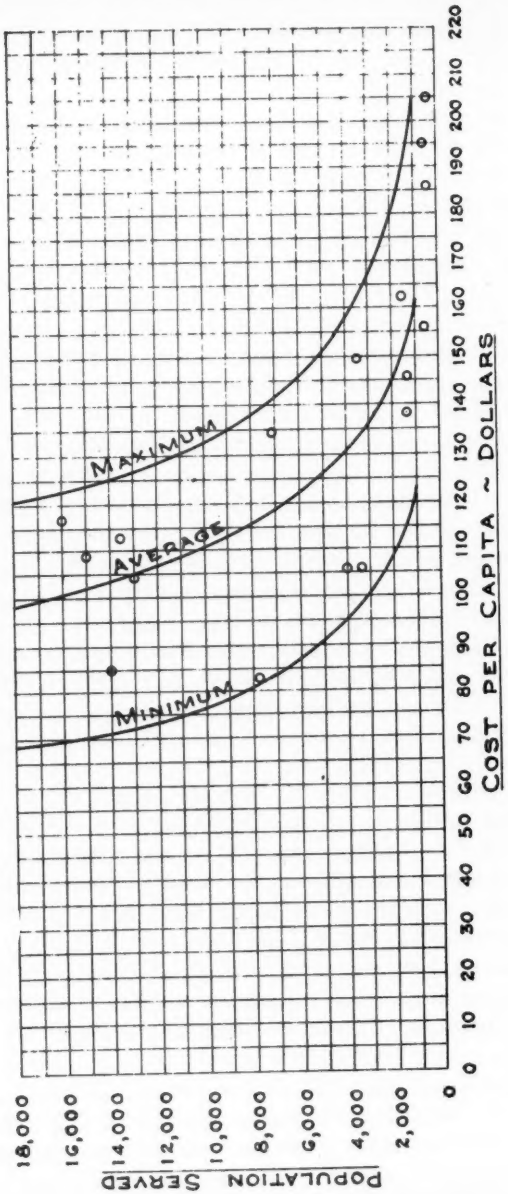
MAXIMUM
AVERAGE
MINIMUM
COST PER CAPITA ~ DOLLARS
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220
POPULATION SERVED
0 2,000 4,000 6,000 8,000 10,000 12,000 14,000 16,000 18,000

FIG. 2

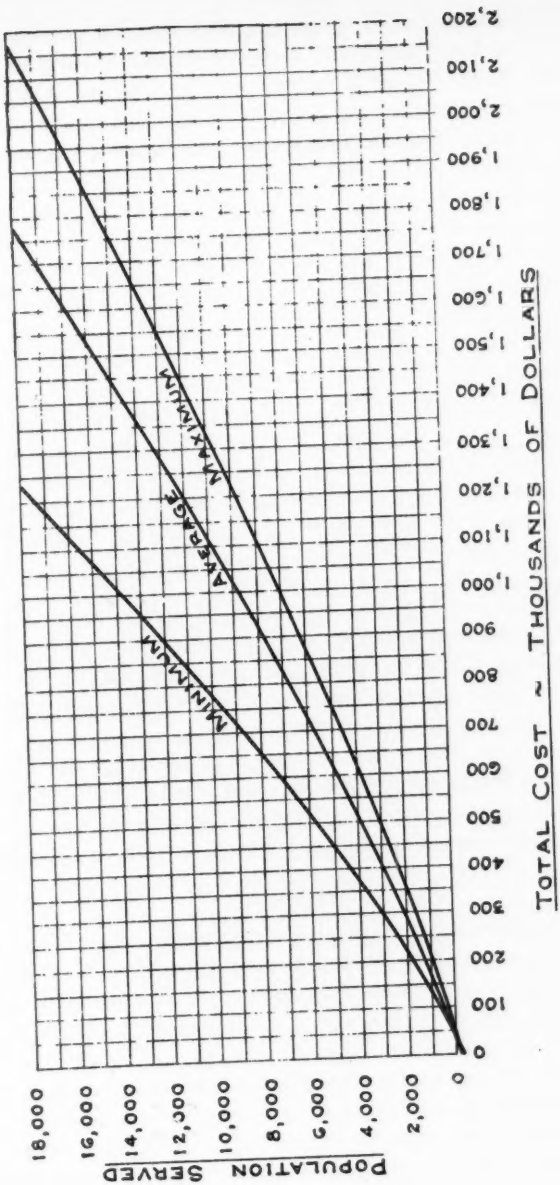
MAXIMUM
AVERAGE
MINIMUM
POPULATION SERVED
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
TOTAL COST ~ THOUSANDS OF DOLLARS
2,200
2,100
2,000
1,900
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0

FIG. 3

diagrams can be multiplied by the following percentage factors. These multipliers for the years 1937 to 1913 inclusive are based on the *Engineering News-Record* Construction Cost Index for Waterworks Plants, published in the June 30, 1938 issue; and for the years 1912 to 1909, on price-trend diagrams prepared by Nicholas S. Hill, Jr., in 1929.

YEAR	INDEX	YEAR	INDEX
1937	100.0	1923	101.5
1936	91.1	1922	89.9
1935	90.2	1921	104.9
1934	90.0	1920	130.5
1933	81.4	1919	110.4
1932	78.3	1918	106.3
1931	85.3	1917	95.7
1930	90.5	1916	66.0
1929	92.2	1915	51.4
1928	87.8	1914	48.0
1927	89.5	1913	51.1
1926	96.1	1912	50.1
1925	98.1	1911	49.1
1924	102.7	1910	50.9
		1909	52.7

The author had hoped to include in this paper the cost of water delivered to the consumer, but time did not permit. As the approach to this question might be quite different from that for the cost of construction, it is suggested that this topic be assigned to some other member of the Association for a future paper.

In conclusion, the author wishes to acknowledge the help given by many waterworks superintendents and others who have furnished information and assisted in compiling the figures that have been used in arriving at the cost of small surface water supplies in New England.

Discussion

Karl R. Kennison.* What is a reasonable cost? When a community starts out to develop a supply, how can it tell whether it is getting a bargain or paying too much? Mr. Sampson has made an attempt to develop a representative average figure, which does not exist in any individual case. However, his figures are very interesting. His curve of cost per capita receded to a lower and lower cost up to a certain population, and it may be that towns of about a certain size can expect to get a water supply fairly cheap, but beyond that size the curve may reverse itself and a very large municipality or

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metropolitan district may possibly have to pay more for its water.

To get data for answering this question, we must first define what we mean by the cost of a supply. This is difficult because we seldom start from scratch and develop a complete new supply from the ground up, but rather in steps, and often the individual steps are only partially completed at one time. This is particularly true of the distribution system. Forgetting for the purpose of this discussion the distribution system and considering the cost of the works supplying the distribution system, I would define the cost of any increment of the supply as the capital expenditure made for it and for its initially adequate delivery to the distribution network. In the case of a new supply for a large district, one seldom makes a first connection from the source of supply to the district that is adequate to deliver the entire supply developed. One establishes a capital account and keeps adding to it by new construction as the years go by. But what a town wants to know in developing its water supply is, what have we got to pay now to get something that is satisfactory now and that we can be sure of satisfactorily maintaining in the future? We have got to develop more than we need right now, but we do not have to build pipe lines as big as we will have to have fifty years from now. We should use the unit of cost per million gallons per day delivered, because cost per capita is not a satisfactory unit in which to express the cost of such developments. How can we tell whether to use the present population or the population for which the system is designed? Perhaps we have already made some other expenditures in the past for serving the same population.

A few figures may be interesting. Large surface supplies for big districts like the metropolitan districts in Boston and Hartford involve principally the cost of large reservoirs. Wachusett Reservoir, when it was built about 1895 to 1906, cost about $13,000,000, including the watershed protection. Its available or useful capacity is 56 billion gallons, and its safe yield at the time it was built was about 100 million gallons a day. Hence the cost per million gallons a day, of the reservoir alone, was $130,000. A large portion of the watershed has since been given to Worcester, so that the safe yield at the present time is only 85 million gallons per day.

Quabbin Reservoir, now being built, is an exceptional reservoir in that it serves two watersheds, the Swift and the Ware, and has a tunnel connection. There are also other works connected with its development. The total cost of the reservoir, including the Ware and all connections, will be about $42,000,000, and it will supply 194,000,-

000 gallons a day, at a cost of $216,000 per million gallons a day.

The Nepaug reservoir of Hartford cost $1,371,500, and has a safe yield of 24,000,000 gallons a day, at a cost of $57,000 per million gallons a day. However, that does not include any cost of diversion damages. It was built in 1914 to 1917, and it has been stated here that the cost is twice as much today as it was then.

We must be careful in interpreting such statements. We can't multiply the earlier figure by two, because if we were building that reservoir today we might not build it by the same methods. The entire development of a supply today is affected by present conditions as to cost and methods of construction. Our 26-mile tunnel for Quabbin Reservoir could not have been built for the same money twenty years ago. Possibly we would not have developed the supply in the same way thirty or forty years ago. When Wachusett Reservoir was built, the entire bottom was stripped of soil. Labor was cheaper then. Just because prices are twice as much today does not mean that we can multiply the earlier prices by two in making our comparisons.

The metropolitan system is exceptional in that the District did not start off in 1895 to develop a new supply, but had to purchase supplies from Boston and add to them, writing off the obsolete works that were not of any use, such as the Mystic supply. Regardless of how they got it, as a matter of fact they had to spend nearly $42,000,000 to get their supply. They got at that time a safe yield of 160,000,000 gallons a day, which cost $259,000 per million gallons a day.

The Ware and Swift supply, now near completion, will cost $50,000,000. We might be justified in subtracting from that the cost of a lot of things that have nothing to do with Ware and Swift, but as a matter of fact they were considered necessary, and actually the total work done as a part of the development cost $50,000,000 and resulted in an additional yield of 208,000,000 gallons a day, which is $240,000 per million gallons a day. I do not see any practical way to express that in per capita cost.

Note that the yield of the original district development which, as stated, was 160,000,000 gallons a day and cost $259,000 per million gallons a day, has now been reduced to 112,000,000 gallons a day, to which we add the Ware and Swift, making 320,000,000 in all.

So much for the cost of the different steps in the development. In addition, we have to spend money all the time not only for what might strictly be called maintenance but to take care of obsolescence

and also for additions to the works for getting the supply into the distribution system. Hence I suggest that a definition of these other costs, which ought to be expressed in so many dollars per million gallons, should include all other expenditures for maintenance of the source, and treatment works, and also the fixed charges, the direct annual expense, whatever may be the method of financing, for additions and replacements in the delivery system. That is quite an item. In the Metropolitan District, it will be quite an item in the future, because it is now found necessary to make large expenditures, not for any new sources of supply but simply to replace obsolescent works and to make additions to the main distributing aqueducts. We are going to build a large pressure tunnel which will eliminate a lot of other expense, and which, in the not too distant future, may not cost any more annually per million gallons. These costs per million gallons should include the fixed charges on additions like this pressure tunnel, not the construction costs but the fixed charges on them. They are in the class of maintenance costs. I am not speaking of the distribution system but simply trying to express the additional cost which we have to spend from year to year over and above the previously discussed figure for developing the supply itself or an increment of the supply and entirely in addition to the ordinary maintenance of the distribution system.

This continuing cost per million gallons distributed to the District has, since the beginning, increased materially. A few years after the Wachusett construction it was only about $15 per million gallons, but these early years are not typical. We are now spending $40 per million gallons for maintenance of the sources and of the works that bring in the water and for fixed charges or direct expense, as the case may be, to take care of obsolescence and additions.

METHODS AND COSTS OF DEVELOPING GROUND WATER SUPPLIES IN NEW ENGLAND

BY PAUL F. HOWARD*

[*Read September 14, 1938.*]

A study of the cost of ground water developments for municipal water supplies requires consideration of the procedures involved in the development of such supplies.

Preliminary Investigations

Experience has shown that the ordinary community in New England requires on the average for each service connection about 250 g.p.d. of water, about 600 g.p.d. during the maximum week and about 800 g.p.d. to satisfy the peak day's demand. On this basis, a ground water development to supply a community having one thousand service connections would require wells from which water could be taken at the rate of 800,000 g.p.d. for one day, 600,000 g.p.d. for one week and 250,000 g.p.d. on an average.

In general, an examination of the topographical surveys published by the United States Government is helpful in locating areas that may have a watershed sufficiently large to supply the required quantity of water. However, examination of such maps is of no value in glacial formations such as are found on Cape Cod where the bed rock is at a great distance below the surface of the ground and the ground water is free to discharge in many directions into the streams and other bodies of water that abound on Cape Cod.

Experience in this vicinity has shown that where the precipitation is stored in the ground in great deposits of sand and gravel, water can be withdrawn continually at a rate of about 500,000 g.p.d. per square mile of watershed, provided of course, that the ground formation is such as to allow the water to flow readily to wells or other collecting works.

The areas selected to be investigated are usually tested by means of pipe wells in order to determine, to a limited extent, the character of the ground formation, the elevation of the surface of the water in the ground, the ease with which the ground will yield its water and the quality of this water. These pipe test-wells are usually of 2½-in.,

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extra-heavy pipe, driven by the wash method and costing about $3.00 per foot if the pipe is left in the ground and about $2.00 per foot if the pipe is withdrawn and salvaged.

Pumping Test. After an area has been located by means of individual test wells and it appears to meet the requirements of the proposed ground water development, it is generally tested by installing a sufficient number of these pipe wells to allow development of the desired rate by joining the wells together temporarily and pumping from them collectively. The wells while being tested are generally pumped at rates varying from 15 to 30 g.p.m. per well and are usually pumped at a combined, or collective, rate about equal to the expected average daily demand. Thus a development to supply 250,000 g.p.d. on the average would require that about eight wells be joined together and pumped at a combined rate of 175 g.p.m.

The joining of these wells together and pumping them continuously for a period of one to two weeks costs about $50 per day. A summary of the cost of such a preliminary investigation might be listed as follows:

15 individual test wells, say 50 ft. deep, driven and withdrawn @ $2.00 per ft.	$1500
8 individual test wells, driven and joined together for test purposes, say each 50 ft. deep @ $3.00 per ft.	1200
10-day pumping test @ $50.00 per day	500
	$3200

If the ground formation is so fine as to require well strainers for testing, these generally cost about $12.00 each.

Another method, sometimes adopted after having located by means of individual test wells an area that seems to be favorable for the desired ground water development, is to drive two of these wells about two feet apart and then to pump from one of them at a high rate, say 50 to 100 g.p.m. and to observe the lowering of the water level in the other. From such a test, estimates are made of the probable yield of a gravel-packed well, so-called, built at the location of the two test wells and with a radius equal to the space between these wells. Such tests cost about $1.00 per hour and are usually run for a period of one or two days.

When such tests indicate that a sufficient quantity of water can be obtained to warrant the investment, a gravel-packed well is built and the actual test of the yield and the quality of the water is made on this well. Then, if need be, more gravel-packed or other wells

are constructed until the desired quantity and quality of water have been obtained. This method is generally used by contractors offering to develop water supplies and to guarantee the yield of the wells and the quality of the water.

In developing the water supplies for the Town of Harwich and the Cotuit Fire District, both on Cape Cod, the author felt sufficiently certain of the areas selected by the results from four or five individual test wells at each location, to risk his reputation as an engineer and advise his clients to build permanent gravel-packed wells and conduct the pumping tests on these, thus saving the expense of installing individual pipe wells for a pumping test. The results were entirely satisfactory.

It is not, however, always so easy to obtain a ground water supply on Cape Cod. Only this year while investigating for a water supply for the Centerville-Osterville Fire District located close to the Cotuit Fire District, it was necessary to drive forty-one individual test wells before locating areas that appeared favorable for a suitable ground water development. Two areas were found, the combined yield of which will meet the estimated requirements of the District. One was tested at the rate of 250 g.p.m. minute by pumping from fifteen test wells and the other at the rate of 150 g.p.m. by pumping from six test wells. The driving of these sixty-two wells and the testing cost $8,100.

Permanent Construction

In general, today the three principal types of wells being used are: (1) large open wells sometimes called dug wells, (2) tubular wells usually constructed of 2½-in. pipes driven into the ground, (3) gravel-packed wells, usually constructed by placing selected gravel about a large pipe and strainer through which the water is drawn from the ground.

Many factors besides initial cost must be considered before selecting the type of well for any particular water supply development.

Rate of Pumping. Large open wells, that is, dug wells, have been used where it has been desired to pump water at a high rate for a short time, thus taking advantage of the storage capacity of the well, and then allowing the well to fill up over a relatively long period when not pumping. This method, however, does not allow for obtaining the maximum yield of the well as such a well's maximum yield can only be obtained by pumping at such a rate that the water level is lowered in the well to the maximum safe depth at all times.

Water supplies developed by means of tubular wells, that is, driven pipe wells, usually 2½-in. in diameter, have in the past been the most common means of securing a ground water supply. Experience has shown that wells of this kind cannot successfully be pumped at high rates and a value of 10 g.p.m. has come to be considered the maximum safe yield of this kind of well, although a study of the average yield per well of many installations was found to be about 7 g.p.m. The rate of yield of these wells is greatly reduced in time by clogging, due to the fact that when a well of this type is pumped at the rate of 10 g.p.m. the water at the entrance to the well is traveling through the sand at a rate of about 70 ft. per minute. A water supply development by means of driven wells should be built to supply the maximum day's demand without causing the tubular wells to be pumped at a rate greater than the design rate which, as stated, is generally taken at 10 g.p.m. per well. The result of such a development is that on the average the wells are only pumped at a rate about one third of their individual capacity, although the area being pumped from may be yielding its average capacity, the water supply for the peak demand being taken from water stored in the ground, to be replaced during periods of lower draughts. Many a ground water development by means of tubular wells has been seriously damaged by pumping the wells at an excessive rate. Wells of the tubular type are at their best when they can be pumped at a uniform and low rate.

Wells of the gravel-packed type are being installed quite frequently nowadays. In general they may be pumped readily at various rates, and at what may seem high rates, without doing damage to the wells if they are carefully constructed and conservatively designed. A well of this type, 4 ft. in diameter and having a gravel-packed depth in water-bearing formation of 50 ft., yielding 1 m.g.d., would only have a velocity of water through the interstices of the sand and gravel at the entrance to the well of about 5 in. per minute. Thus, it may be seen that wells of this type may be pumped at what seem to be high rates, without clogging the wells or the ground about them, and that the rate of pumping from such wells can be increased to take care of the peak demand by pumping water temporarily from storage in the ground at high rates, without damaging the wells. The rates of pumping depend, of course, upon the character of the ground being such as to yield the water at the required rate.

Ground Formation. Dug wells have generally been constructed to obtain water from one water-bearing stratum, although sometimes

they have been built, not only with an open bottom, but with holes through the sides at various levels to pump water from various water-bearing strata. This was done at Canton, Mass. Later the holes left to pump water from the uppermost strata were closed by means of a wooden plug driven from the inside, as it was found that this water was of poor quality at times of high-water level.

Driven wells are constructed with an open end and perforations at the lower end or with a well strainer, thereby pumping water from one stratum, although of course, two separate wells may be located in different strata and yet be joined together to a common suction conduit.

Wells of the gravel-packed type have the distinct advantage of being readily constructed to take water from any one of several water-bearing strata or from all of them, as may be desired, the water from any undesirable stratum being held back by building a concrete seal in the well at the elevation of the undesirable water stratum.

Iron and Manganese. The water from many dug wells has been satisfactory when the wells were first built, but gradually, over a period of years, the iron and manganese content of the water has increased to an excessive degree. This likewise, as has already been stated, has been the experience with driven wells even to a greater extent, probably due to pumping these wells at too high a rate. Gravel-packed wells have not been used in this vicinity long enough to cite any long-time experience record. However, they do seem to have less of the iron and manganese troubles when conservatively designed and built than other types of wells. There have been, however, some reports of the growth of *Crenothrix* and *Leptothrix* in gravel-packed wells. Whether these growths will become extensive enough to cause trouble, as they sometimes have on the West coast, is yet to be seen.

Corrosive Quality. Experience has shown that the corrosive quality of the water from wells is increased as the water level in the well field at the wells, is lowered. Therefore, the particular type of well installation that will lower the ground water level the least for any particular development will be the most favorable so far as the corrosive quality of the water is concerned. Tests made on an open well built by means of a concrete curb and open at the bottom, at Canton, Mass., showed that the carbon dioxide content of the water increased almost directly with the lowering of the water of the well, and, of course, that the pH of the water was lowered as the carbon dioxide content increased.

Pollution. Large open or dug wells built of concrete in low areas subject to flooding are reasonably safe against pollution provided the concrete curb is carried sufficiently high and the ground formation at the well is such as not to allow the polluted flood waters to enter the well. Many of these wells, however, were built some years ago with brick, and the walls have cracked so that the well water is subject to pollution at times of flood.

Driven wells with their many well connections, all of necessity operating under a vacuum, are not well adapted to low areas that may become flooded with polluted water.

Wells of the gravel-packed type that are built in low areas subject to flooding, with proper concrete seal near the top, are not so apt to become polluted at times of flood because there are few well connections, and if the wells are built with turbine pumps situated down in the wells, the water discharged from them into the well connections is under pressure, thus preventing the entrance of flood water.

All three types of wells are equally subject, when poorly located, to sub-surface pollution from sewers, cemeteries, and the like.

Area of Land Required. Although the actual area of land required for the physical installation of wells of the dug type and gravel-packed type is less than that for the driven type, this consideration does not usually enter into the matter of the kind of well to be used, since the area of land required for protection of the quality of the water supply is far in excess of the area required for the physical installation.

Maintenance Cost. The maintenance cost of all types of wells is relatively low when compared with other parts of a water system. This is perhaps particularly so of large dug wells and gravel-packed wells. About the only maintenance cost connected with large dug wells is the matter of maintaining the usual wooden roof structure, and this has been eliminated in some cases by building a roof of masonry construction.

What experience there has been with wells of the gravel-packed type seems to indicate that the cost of maintenance is practically negligible, provided the wells are conservatively designed and properly built.

Tubular pipe wells have been the most expensive to maintain because it is necessary, in many installations, to wash the wells out to remove the sand, gravel, etc. that have entered them and, in the case of wells built with strainers, to blow them out (so-called) by introducing steam, air or water under pressure into the well to free

the material gathered about the openings of the strainers. The washing out and reconditioning of these wells usually costs about $7.00 per well. Since it is necessary to join wells of this type together by means of pipes through which the water is drawn under a vacuum, it is necessary to keep all the connections air-tight. This has proved in many cases a hard and expensive thing to do, the flexible lead goosenecks used in each well connection having been the source of much trouble and expense. This trouble has been somewhat lessened by using copper goosenecks. Nevertheless, there have been many well fields of the driven type, which were carefully built under favorable conditions, that have been in operation for many years and have required practically no expense for maintenance.

Construction Costs

Dug Wells. Municipal ground water supplies were obtained in New England generally during the latter part of the last century by means of large open wells, that is, dug wells. However, not many large dug wells have been built in recent years.

At Canton, Mass., about ten years ago, a large dug well was built of concrete, 35 ft. in diameter and 20 ft. deep, having a capacity of 400,000 g.p.d. of water. This well has a wooden roof and cost, exclusive of payments for engineering and land, $15,000. A brick pumping station one story high, 8 ft. by 21 ft. in plan was also built, to house the pumping equipment, at a cost of about $2,000.

At Newton, Mass., a year ago, two large dug wells were built of concrete, each 20 ft. in diameter, one being 33 ft. and the other 40 ft. in depth. Each well had a flat-slab, concrete roof upon which was built a brick pumping station about 12 ft. square in plan. These two wells, together with their accessories and grading, but exclusive of pumping equipment, cost about $17,500 and are each estimated to have a yield of 1 m.g.d. It should be noted that the cost of these two wells does not include the cost of testing to locate the water supply or to determine its quality.

Tubular Wells. For a period of about fifty years, most of the ground water supplies in New England have been developed by means of tubular wells.

In 1931, the town of Yarmouth, Mass., developed such a supply having a capacity of about 350,000 g.p.d. Costs were as follows:

8 individual 2½-in. pipe wells were driven to locate a probable source of water supply and later were withdrawn, at $2.10 per ft., or a total cost of	$ 741
6 wells were driven upon which to make a pumping test, together with 4 observation wells. Later 8 wells were added to the original 6, making a	

total of 18 wells driven and left in the ground at a cost of $2.85 per ft., or a total cost of 2,061
14 well strainers were installed at a cost of 210
14 well connections, each consisting of 2½-in. pipe, 2½-in. gate valve, gate box and 2½-in. flexible lead gooseneck were installed at a total cost of 1,253
Pumping test 349
8-in. suction main furnished and laid at $4.00 per ft. 1,280
TOTAL COST OF YARMOUTH INSTALLATION $5,894

At Buzzards Bay a year ago, a somewhat similar installation was built, having a capacity of 400,000 g.p.d. This cost as follows:

6 individual test wells to locate a probable source of water supply, driven and withdrawn at $2.00 per ft. ..... $ 700
10 wells were driven upon which to make a pumping test, together with 1 observation well, the water level being determined in some of the wells being tested, by means of small pipes inserted in the wells. Later 15 wells were added to the original 10, making a total of 25 wells driven and left in the ground, at $2.65 per ft., or a total cost of 2,371
25 well strainers 750
7.2 days of pumping test 259
99 hours of pumping on individual test wells 99
100 ft. of ¾-in. pipe for measuring level of water in wells 25
25 well connections 1,353
311 ft. of 8-in. cast-iron suction pipe 1,828
TOTAL COST OF BUZZARDS BAY INSTALLATION $6,909

A saving of about $450 was made in the cost of well connections at Buzzards Bay by using flexible Dresser couplings made of steel and well coated with Bitumastic Enamel in place of the usual lead goosenecks.

The town of Townsend, Mass. developed a water supply three years ago, having a capacity of 430,00 g.p.d. Development by means of tubular wells cost as follows:

Twenty-five 2½-in. pipe wells were driven and left in the ground, at a cost of $2.50 per ft., or a total of $3,667
6 wells driven and withdrawn at $1.55 per ft. 662
Testing individual wells, etc. 219
5 days of pumping test 300
35 usual 2½-in. well connections 2,082
364 ft. of 8-in. cast-iron suction main, furnished and laid 1,311
307 ft. of 6-in. cast-iron suction main, furnished and laid 1,043
TOTAL COST OF TOWNSEND INSTALLATION $8,875

At Townsend, individual test wells to locate a probable source of water supply were driven many years previously, but no cost records of this work are available.

From these figures, it can be seen that the cost of developing these three water supplies varied from $1680 to $2060 per hundred thousand gallons of water supply per day developed. It is to be noted that these figures do not include the cost of land and engineering.

The costs of developing these three water supplies including land, engineering, pumping equipment, pumping stations, grading, etc. were as follows:

YARMOUTH. Wells, piping in well field, 240-g.p.m. electric-motor-driven pumping-unit, 240-g.p.m. gasoline-engine-driven pumping-unit, concrete-block pumping-station and office, engineering and land $16,000
or, $4,500 for each 100,000 gallons per day capacity.
BUZZARDS BAY. Wells, piping in well field, two 275-g.p.m. Diesel-engine-driver pumping-units, brick pumping-station, engineering and land $25,000
or, $6,200 for each 100,000 gallons per day capacity.
TOWNSEND. Wells, piping in well field, one 300-g.p.m. electric-motor-driven pumping-unit and one 300-g.p.m. Diesel-engine-driven pumping-unit, brick pumping-station and office, wooden two-car garage, engineering and land $33,000
or, $7,600 for each 100,000 gallons per day capacity.

Gravel-packed Wells. In 1936, the town of Harwich, Mass., developed a water supply having a capacity of 720,000 g.p.d. by means of four gravel-packed wells of the low-velocity type. The wells are each 52 in. in diameter and about 36 ft. deep. The cost of the work was as follows:

Eight 2½-in. pipe test-wells were driven and left in the ground, at a cost of $2.70 per ft. or a total of	$ 549
1 well driven and withdrawn at $1.60 per ft.	55
9 well strainers	135
33 hours of testing on small wells, etc.	94
5 days of pumping test	300
4 gravel-packed wells	6,547
4 well connections of 6-in. pipe and about 700 ft. of 8-in. cast-iron pipe to connect wells	2,600
TOTAL COST OF HARWICH INSTALLATION	$10,280

A similar development in the same year at Cotuit, Mass., of equal capacity, cost $7,700.

The cost of developing these two water supplies was $1430 and $1070 respectively per 100,000 gallons of water supply per day developed.

These figures do not include the cost of land and engineering. The wells and the areas in which the wells are built at both of these locations have a considerably greater capacity than that for which they have been developed.

Each of these installations cost for the following:

4 gravel-packed wells, piping in well field, 500-g.p.m. Diesel-engine-driven pumping-unit, 500-g.p.m. gasoline-engine-driven pumping-unit, brick pumping-station and office with office equipment, two-car wooden garage, hard-surface roading, grading, engineering and land, about $38,000
or, $5,300 for each 100,000 gallons per day capacity.

About two years ago a water supply was developed for the town of Needham, Mass. by means of a gravel-packed well for a capacity of 1 m.g.d. The details of this development have been reported in this Journal. The cost of this work was as follows:

Test wells and testing	$ 2,400
Gravel-packed well, 92 ft. deep	8,600
Diesel-engine-driven pumping-unit	10,000
Pumping station 18 ft. by 27 ft. and miscellaneous cost	9,000
Total cost of development, exclusive of land and engineering	$30,000

Several municipalities have developed ground water supplies by means of gravel-packed wells and required the contractor doing the work to guarantee the capacity of the development and the quality of the water for periods varying from one to five years.

The city of Woburn has let three such contracts. The first was for a water supply of 750,000 g.p.d., including well, turbine-type equipment, small well house and accessories at a cost of ....$28,000.

The second was for a water supply of 2.5 m.g.d. at a cost of $52,000

The third was for a water supply of 3.0 m.g.d. at a cost of $109,000

These figures do not include the cost of land, engineering, pipe, etc.

The subcontractor who built the two wells, together with the two small well houses, each about twelve feet square, and furnished the electric-motor-driven pumping-equipment, under the last contract, received $82,000 for that portion of the work.

A water supply development of 1 m.g.d. capacity, built on a guarantee basis at Billerica, Mass., consisting of two gravel-packed wells each about 40 ft. deep and 4 ft. in diameter, together with a low-head turbine pump, located in each well, an aerator and two high-head electric-motor-driven centrifugal pumps, cost ....$35,000.

Conclusion

It is quite evident from these studies that, so far as the cost of the actual water supply development is concerned, i.e. cost of constructing the wells and piping them together to a common point, no general conclusion can be drawn as to which type of well development is the most economical. There are usually other factors of more importance that affect the choice of the type of well to be used. The cost of the total water supply development, including the pumping equipment and pumping station, varies a great deal depending upon the type of pumping equipment selected and the size and character of the pumping station built.

BUTT-WELDED STEEL STANDPIPE AT SCITUATE, MASS.

BY WILLIAM J. LUMBERT*

[*Read September 16, 1938.*]

In 1931, the Town of Scituate, Mass. took over the privately owned water system. At that time, with peak loads of more than 1¼ m.g.d., the total storage capacity, in the available standpipe, was 270,000 gal. It was quite apparent that more storage was needed and that at least one new standpipe and possibly an elevated tank should be erected. The Water Commissioners attempted in several town meetings to obtain authority to borrow money on notes, to be paid out of earnings by the Water Department. It was not, however, until November 29, 1937 that such authority was granted.

After investigating the conditions carefully, it was decided to erect a standpipe on a high point of land near North Scituate. This was not the highest land in the town, but it was situated about 1½ miles nearer the centers of population and only 6 ft. lower.

Arrangements were made to borrow $40,000 at 2% for 10 years, beginning January 1, 1938. This amount was to cover the cost of the standpipe, foundation and connections to the system. Because of the serious unemployment situation it was decided to start part of the work at once, using money from the general funds to pay for labor; and more than 100 men were employed during December 1937, laying about 2200 ft. of 14-in. Transite pipe.

Design. Several designs were made for standpipes of riveted and welded construction. The final decision was for a butt-welded tank having a diameter of 55 ft. and a height of 70 ft. from the base of the water line. A reinforced concrete slab and ring foundation was designed to meet these conditions and this construction was also completed in December 1937. The concrete ring was poured one Saturday afternoon and the steel reinforcement placed; and the concrete slab, covering the entire area was poured the next day.

Standard specifications for a butt-welded steel standpipe were not available from the Water Works Associations or the American Welding Society, but several tentative specifications were readily obtained and considerable detailed information was accessible in the records of the societies and steel fabricating companies. A considerable amount of experimental work has been done in the fabrication and testing of

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BUTT WELDED STANDPIPE - SCITUATE, MASS.

welded joints. The tensile strength designated for the shell plates was 15,000 lb. per sq. in., except for the lower course, where, in an attempt to minimize bulging, the tensile strength used was 12,000 lb. per sq. in. Figures showed that a bulge of ⅛-in. might be expected, and a straight edge placed vertically on the plates before and after filling with water, showed this amount of distortion. All steel for plates and rolled shapes was made by the open hearth process and was to conform to the requirements of the Standard Specifications for Structural Steel of the A.S.T.M. (mild steel specification A-10-current). The roof plates to be of copper-bearing steel.

The thickness of the bottom and sketch plates as determined by the formula $t = \frac{H + 125}{600}$ was ⅜-in, and the design called for the thickness of the foot plates to be equal to the thickness of the bottom plates plus ½ of the thickness of the lower course of shell plates. This thickness was found to be 11/16-in. The thickness of the shell plates was figured in the ordinary way, using the formula $t = \frac{5.21\ rh}{t_s}$ where r = radius and h = height of water from a point 12 in. above the center of the horizontal weld and t_s = tensile strength. As an additional factor of safety against corrosion, 1/16 in. thickness was added to the net figure. To eliminate as much welding as seemed feasible, the number of courses was limited to nine, even though the figured estimate for ten courses was somewhat lower. The thickness of the three upper courses was arbitrarily set at 5/16 in. The thickness of the roof plates was limited to not less than 3/16 in.

Construction. A 1:1 cement sand cushion 1½ in. thick was spread on the concrete base just before the bottom plates were laid; strips of tar roofing paper 20 in. wide being laid under all seams. The paper kept the sand and cement away from the joints, but I would recommend using a heavy roofing paper the full width of a standard roll. This would not only be easier to place and control in a wind but would give added protection due to the width.

The sketch plates were cut as required and then the bottom side of the bottom plates, sketch plates and foot plates was sand blasted and given three coats of Truscon corrosion-resisting paint, the trade name of which is Bar Ox Kromo Kote. This paint possesses a very high percentage of inhibitive pigment as well as being long in oil, thus assuring maximum resistance to weather conditions. The foot plates were flat over their entire surface, lap-welded to the

sketch plates and butt-welded to each other. A piece of 3/8-in. steel, 4 in. wide and as long as the joint, was placed under the butt weld at the ends of the foot plates and securely welded to both plates, forming a backing strip for the weld.

Perhaps the most serious consideration in the design of the tank was given to the welding involved in the joint between the foot plates and the lowest course of shell plates. The amount and disposition of weld metal appears to be a vital factor, although there are three distinct lines of thought. In one case the larger weld is on the inside as a tensile resistance to bulging of the lower plate; another case had an equal amount of weld metal on either side to equalize the stresses set up in the foot plate; the third case had less weld on the inside to decrease the distortional stresses in the foot plate at the contraction seam. The sum of the throat distances of the inside weld and that of the outside weld as determined by formulae and experiment was practically equal to the thickness of the shell plate. Several sets of plates having the same thickness as the foot plates and shell plates were placed in the proper relative position and firmly held and welded, to examine the stresses set up in the plates. The total throat distance was 31/32 in. and one set of welds showed 3/8 in. on the outside and 5/8 in. on the inside, the next set showed 1/2 in. outside and 1/2 in. inside, and the third set showed 5/8 in. outside and 3/8 in. inside. The heavier weld as expected, created considerably more stress in the steel plates. With the heavier weld placed inside, more resistance was offered to the bulging of the lower-course plates, but incidentally more stresses were created in the part of the foot plate that was inside of the tank and this might have created considerably more difficulty in welding the contraction seam between the foot plate and the sketch plate. This latter seam was not welded until the shell plates were well up.

For the vertical seams on the four lower courses, the plates were planed on both sides in such a way that when placed in position, with a space of 1/8 in. between plates, the angle to be filled with weld metal was 60 degrees, the vertex of the angle being at the center of the thickness of the plate. The vertex of the angle on the plate itself, was planed off so that a flat space 1/8 in. wide was left on the edge of the plate. This arrangement showed a 1/8-in. square open space between the edges of the plates when they were placed and ready for welding. Both sides of the lower edges of the plates for the horizontal seams on the lower courses were planed so that the angle of opening, when the plates were set in place, ready for welding, was

45 degrees. The upper edge of each plate was planed square, making the lower side of the angle, horizontal. The plates were planed on both sides in such a way that the vertices of the angles were ⅛ in. apart.

The vertical edges of the plates in the upper courses were planed on the inside, only, in such a way that the angle of opening for the weld metal was 60 degrees. The vertex of the angle on the plate was planed so that there was a flat space ⅛ in. wide, on the outer edge. These plates were set ⅛ in. apart forming a space ⅛ in. square for the outside bead. The vertex of the angle was at the outside surface of the plate. The weld metal in the vertical seams on the upper courses was placed from the inside, with the exception of the bead on the outside. For the horizontal seams in the upper courses the lower outer edge of the plate was planed off at an angle of 45 degrees, with the vertex 1/16 in. from the inside edge. The top edge of the plate was planed flat making the lower side of the seam horizontal. The weld metal in these seams was placed from the outside except for a bead on the inside.

The roof plates were welded directly to the upper edge of the top course of shell plates with a 3/16-in. bead. The floor and roof plates were lapwelded, the lap being 2 in. and the bead equal to the thickness of the plate. The roof was supported on eight trusses that rested on the stiffener angle which was welded to the inside near the top of the tank. The trusses were built up with channel and H beams, the outer ends being welded to the stiffener angle.

After the lower course of plates was assembled, the vertical seam on the next course was placed one third of the length of the plate from the vertical seam on the lower course and the vertical seam of each successive course was shifted the same distance around the tank in the same direction, thus breaking the vertical seams over a space equal to the width of two plates (15½ ft. in this case), rather than the customary single plate. The contractor was not allowed to make any holes in the plates for assembly purposes, and short horns, of ½-in. steel, were used to set the plates for tack welding. The horns were tacked in place for setting the plates and removed after the seams had been welded. Angles that were used to hold the staging were tackwelded, and removed from the tank as the staging was brought down to the ground from the top. Measurements of the outer circumference of the lower shell course showed a shrinkage of 9/16 in. per hundred feet of circumference, after the seams were all welded.

Erection of steel was started April 4, and completed on April 30, 1938, with a total of twenty-two working days, placing and welding 154 tons of steel. There were 3953 ft. of welding, using 116 lb. of 5/32-in., 596 lb. of 7/32-in., 988 lb. of 3/16-in., and 439 lb. of 3/16-in. wires, a total of 2139 lb.

Painting. Painting of standpipes is a very important consideration as there is a large capital investment that depreciates rapidly if neglected, and the painting of steel is particularly interesting in that many factors, sometimes very complicated, are involved. The problem, however, has been sufficiently well solved to know the reasons for corrosion, the materials that may be used to prevent corrosion, and the methods of application of these materials economically. If a protective coating on steel is omitted, deterioration by corrosion is more rapid than decay of wood or other materials, and it is, therefore, particularly important to prevent, as far as possible, the tendency of steel to return to its lethargic union with oxygen. This return may be by electrolysis, or electro-chemical action. It is apparent, therefore, that if a protective coating impervious to water and resistant to electrolysis could be applied to the steel there would be no corrosion.

Good paint for good protection of steel should be: (1) Chemically permanent; (2) chemically inert toward steel; (3) resistant to physical damage; (4) impervious to air or moisture; (5) flexible in expansion and contraction; (6) rust inhibitive.

A.S.T.M. and A.S.M.P. tests indicate the best type of pigment and vehicle, and the manufacturer processes these ingredients to meet the requirements for steel paint. Applied by experts, the variations in the paint coat are not great, but careless application shows a very great difference in the results.

Steel arriving on the work is covered with mill scale. This is a protective coat acquired by the steel immediately after coming through the last roll pass, and is an excellent, if not the best, coating that the steel can have, but it will not remain in place on the steel, nor has there been any method developed to make it do so. Because the mill scale flakes off easily, the only way to insure protection is to eliminate the scale entirely. This is best done by sandblasting the surface of the steel. Allowing the mill scale to rust off requires considerable time and is not feasible for water systems, inasmuch as the tank is sorely needed, frequently for years, before it is erected. A pickling process recently set up at some plants is fairly new and while it may be the right way to eliminate scale, it is still untried over a period of time. The sandblasting must be carefully done by

skilled workmen. The mill scale must be adequately removed, and yet the blast must be definitely controled. If small areas of scale are left they will give way even under the paint. Blasting leaves the steel in a somewhat nascent state and the paint must be applied the same day to prevent the formation of rust film. Certain types of paint, such as that used in Scituate, presumably protect the surface despite the thin film of rust, but the difference in cost of application would be less than ½%, and it is obviously better to paint on the same day. The sandblasting on one entire drop had been completed early one afternoon when a shower stopped the work, and although the paint used was selected on account of its particular action with thin rust film, the entire drop was sandblasted again before painting.

The proper use of thinners is very important in painting, and the low-price contractor can frequently make money on material and labor by the misuse of thinners. A paint, however, that is made for application in summer must be thinned for use in fall or winter. Painting although apparently simple, really has many complications. Some of the complications are taken care of by the manufacturers who have shown great progress in developing paints to fill specified conditions, but their applicators are skilled in the profession and they are not hindered by costs. We must, therefore, depend on workmen in the field, at costs consistent with our ability to pay, for close approximation of the manufacturers laboratory tests. The technology of the paint manufacturers is apparently ahead of the application and of painting contractors on whom we depend for successful results.

The materials selected for painting the Scituate tank were non-oxidizing, chemically-stable paints. Both exterior and interior surfaces were treated with three-coat applications, the first two coats in each case being Feroleum B.L 20 S metal primer. This material produced a greater coverage per gallon than was figured, but as far as could be detected during the application, the results were satisfactory. The finish coat for the interior surface was Feroleum Marisol No. 10 Black, a special material, in which, both the pigmentation and the film are not only impervious to water, but, after drying, also completely tasteless and non-toxic. The final coat on the exterior of the tank was Feroleum Algonquin Gray metal finish, the film of which we believe to be impervious to condensation and all weather conditions.

These materials were chosen because the vehicle is not subject to oxidation. It hardens by a process of molecular change, instead of drying through the absorbtion of oxygen and is of such a character as neither to give off nor to absorb any elements whatsoever in contact

with either atmospheric oxygen or water. This paint coat, which was carefully and properly applied, after the steel was thoroughly cleaned, by sandblasting and wiping with cloth, should provide a rust free surface for many years.

Acknowledgments. The tank was erected by the Pittsburgh Des Moines Steel Co.; the paint was manufactured by the Feroleum Products Co. of New York; and the application was made by Trede-nick of Boston, to all of whom I wish to acknowledge appreciation for information.

DIESEL ENGINE OPERATION AT NEEDHAM, MASSACHUSETTS

BY ROGER G. OAKMAN*

[*Read September 16, 1938.*]

The new Diesel engine and pump have been in continuous operation at the Charles River Street Pumping Station since January 25, 1937. A brief description of the layout of this station is necessary to give a picture of our plant.

This equipment is housed in a brick building of Colonial architecture, approximately 18 by 27 ft. inside in plan. The building is one story with a basement, having a large chimney at one end, within which is housed the exhaust muffler from the engine. The muffler is placed in a vertical position and is a Maxim Silencer.

The Diesel engine is a Fairbanks-Morse Company unit of 75-h.p., 2 cycle, solid-injection, single-cylinder type, located centrally in the building. The operation of this unit is carried on from the first-floor level. Connected to the flexible coupling is a Farrel Birmingham Bevel Speed Gear, receiving its power from the engine travelling at a speed of 300 r.p.m. and in turn driving the vertically-connected turbine pump at a speed of 1190 r.p.m. The pump is a Fairbanks-Morse Company, 12-in., 13-stage turbine pump with an 8-in. discharge column connected to a 10-in. discharge line from the station to a 14-in. distribution main in the street, thence to the town.

A separate cooling system is provided for the engine to maintain a constant operating temperature with a minimum differential between the different parts of the engine jacket. A small centrifugal pump, which is driven by a continuous-belt drive connected to the main engine shaft, draws the engine-cooling water from a storage tank, located in one corner of the first floor, through a heat exchanger located in the basement side of the discharge main. This water is circulated through the engine jacket at about 125°F. with a differential of only 5°F. from the time the water leaves and enters the engine. A flow of water is circulated through the heat exchanger from our discharge line by means of a bypass, with the necessary gates and valves, as a cooling medium.

The starting air tanks, aproximately 20 by 60 in. in size, are

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located in the basement and are filled from a 2-stage, water-cooled compressor driven by a "V" belt from a 1-cylinder, 2-cycle, hopper-cooled, 3-h.p. gasoline engine. The tanks carry an air pressure of about 240 lb. per sq. in.

A 3,000-gallon fuel-oil tank is located outside the building and the day tank receives its supply daily from the storage unit. Also housed on the first floor are the lubricating-oil reservoirs and the enameled-steel gauge board on which are mounted the flow meter register and recorder, indicating and recording pressure gauges, recording drawdown water-level gauge and an electric clock.

Since this station is operated without full-time attendance, thermal controls are provided to stop the engine when the cooling water reaches the maximum, safe operating-temperature, and a pressure control is installed on the lubricating system to stop the engine if the oil pressure reaches a lower limit of safe operation. These are the only units for shutting off the engine automatically in case of trouble.

To date, the engine has been shut down twice by the automatic controls; once, due to a break in the belt which drives the water-circulating pump, and once when an insufficient differential was maintained by the cooling system to keep the engine at the right operating temperature. On this last occasion it was a particularly hot day and the room temperature was very high.

As this station operates continuously, we have a schedule of inspections. The pump operator calls at the station at 8 a.m., 12 noon, 4 p.m., 7 p.m., and 10 p.m. The police cruising car makes a duty call from this station at about 2 a.m. At 8 a.m. the daily observations from the different gauges are recorded. At 8 a.m., 4 p.m. and 10 p.m., the fuel tanks are refilled.

The Police Department had occasion to call us one morning when they heard a peculiar knock in the engine. Our own operator, at the 4 p.m. inspection noticed this and shut down the engine. We opened up the side and top plates but could not locate the trouble. Upon starting up again and up to 11 p.m. that night, the knock did not recur. The writer responded to the call from the Police Department at about 3 a.m. and shut off the engine for a more complete examination in the morning. It so happened that we had made arrangements with the Fairbanks-Morse Company to have their men at the station on the following Monday to give the engine its first complete overhaul. This schedule was pushed ahead a couple of days.

After pulling the piston, we observed that the air intake ports were pretty badly carboned. This condition did not allow the proper

amount of air to enter the combustion chambers to provide the proper operation of the engine. Of the five rings on the piston, the top ring was stuck. All wearing surfaces were examined and were noted to be in perfect condition with a minimum amount of wear. The top ring was replaced and the engine assembled, new gaskets replacing the old where necessary. The engine was again put on the line at 7 p.m. This was the first time that the piston had been pulled after 9200 hours of operation.

It is our practice at the first of each month to shut off the engine for an inspection and cleaning of the combustion chambers, exhaust ports, filters, strainers, etc. We drain the oil and flush out the oil reservoirs and refill with clean oil every six months. The monthly cleaning and checking operations take about four hours.

From our observations after our first overhaul, it was decided to pull the piston every six months. On August 29, we again pulled the piston for the semi-annual inspection and overhaul of the engine after 4378 hours of operation. Fairbanks-Morse Company men were on hand to give any assistance and advice that was necessary. The interior was apparently in excellent condition with a minimum amount of wear noted. We replaced the rings on the piston at this time.

I might mention that this speaks well for the quality of the Diesel engine oil that is being purchased from the Atlantic Refining Company of Boston. The fuel oil for our engine is purchased from a local concern, Whetton's Oil Company who are distributors for the James B. Berry Sons Company of Boston.

As this station was designed to supply water to the town of Needham at the rate of 1 m.g.d. and as the size of the mains in our distribution system at this end of the town are of 6 and 8 in., it was desirable to have a pump that would operate efficiently at a high head for a smaller rate of pumping as well as at the desired discharge and head called for upon the completion of our new mains. The program for replacement of these mains extends over a period of five years.

It might be well at this time to note what effect the replacement of small mains with larger ones has made in regard to the output from our pump. Our initial installation required the laying of 7287 ft. of 14-in. bituminous-lined cast-iron pipe to connect with our existing system. At this time we pumped at the rate of 308 g.p.m. or 440,000 g.p.d. from the new well. With the installation of 1986 ft. of 14-in. main to a 6-in. line on Marked Tree Road, we were able to pump at a rate of 324 g.p.m. or 468,000 g.p.d. Upon the completion

of the laying of a 14-in. main on Pine Street this Spring, a distance of 2000 ft. we were able to pump at a rate of 428 g.p.m. or 618,000 g.p.d.

We have just completed the laying of a portion of a parallel line to our 8-in. main on Charles River Street with a new 14-in. bituminous-lined steel water main for a distance of 1800 ft. This has increased our yield at the station to 538 g.p.m. or 775,000 g.p.d.

We expect to complete this extension on Charles River Street early in the fall at which time we expect to increase our output to about 900,000 g.p.d.

It is interesting to note the cost of operation as compared with that called for in the specifications under our original estimates.

	SPECIFIED		ACTUAL	
Pumpage—g.p.m.	350	702	308	538
Total operating head—ft.	309	272	330	315
Water horsepower	27.3	48.4	25.7	42.8
Fuel consumed—lb. per. hr.	17.72	23.89	18.4	24.2
Fuel consumption—lb. per w.h.p.-hr.	0.649	0.494	0.715	0.565
Guarantee—lb. per. w.h.p.-hr.	0.665	0.507	—	—
Cost per million gallons pumped including cost of fuel oil and lubricating oil:				
Fuel oil @ .05¢ per gallon	5.85	3.95	——	——
Fuel oil @ .06½¢ per gallon	——	——	9.14	——
Fuel oil @ .05¾¢ per gallon	——	——	——	6.50
Lubricating oil @ 42¢ per gallon				

It might be well to note the cost of pumping by Diesel-engine power as compared with pumping by electric power at the other Needham pumping stations.

YEAR	TOTAL PUMPAGE M.G.	TOTAL COST DOLLARS	COST PER M.G.	POWER
1934	293	$10,724	$36.5	Electric
1935	301	9,873	33.0	Electric
1936	242	9,255	38.0	Electric
1937	99	4,940	50.0	Electric
1937	146	1,342	9.2	Diesel
1938	39	2,100	54.0	Electric
1938	215	1,700	8.0	Diesel

We carry insurance against a breakdown on any of the equipment. This costs us $133 per year. I believe that this type of insurance is a very good plan as it is, in a sense, another form of protection that is not always considered.

In a study of the figures that have been given, although the actual values do not work out exactly as we figured, we are getting a

much better delivery than was anticipated. With the continuation of a program of replacement and extension of mains, I believe that the total dynamic head will be reduced to the desired head as called for in our specifications; this will ultimately give us a much lower operating cost than we have at present.

It is expected that the total saving on our operating costs for fuel oil, lubricating oil and electric power, since the installation of the Diesel engine will be approximately $8500 after two years of operation. This figure will be further increased after the completion of the work on our distribution system.

Another comparison that we should make is between the cost of the Diesel engine and of electric motors when fixed charges are included.

We shall add to the cost of fuel and lubricating oils, the interest at 4% on the difference between the first cost of the Diesel engine and that of the electric motor. We shall provide for complete depreciation of the Diesel engine in fifteen years with an allowance for annual repairs. We shall not add anything for additional man power as, in my opinion, no more men are needed to operate this Diesel plant than have been employed to operate our electric plants in previous years.

Interest at 4% of difference between Diesel engine and electric motors	$200.00
Obsolescence in 15 years of Diesel engine	450.00
Annual Repairs to Diesel engine	125.00
Total	$775.00
Fixed charges above electric motors for daily operation of Diesel engine	2.12
Fixed charges above electric motors for operation of Diesel engine per m.g. pumped*	2.75
Operating charges per m.g. pumped*	6.50
Total operating charges of Diesel engine versus electric motors per m.g.	9.25

It can readily be seen from these comparisons that at Needham the Diesel power is in all cases much more economical than electric power and that the savings in operating costs will more than equal the cost of the Diesel engine within three years from the time the plant has been in operation.

Summary of Discussion

In the discussion of this paper it was brought out that no direct comparison between electrical and Diesel-engine costs was intended to be given by the figures shown. The electrical costs pertained to

*Present rate of pumping is 538 g.p.m.

the other pumping stations, which do not operate under as favorable a load as the Charles River Street Station. Comparative cost-figures obtained prior to the installation of the Diesel unit were stated to have yielded much closer values for the two types of drive when installed new in the same station.

OPERATION OF NEW FILTER PLANT AT BIDDEFORD, MAINE

BY EDWIN T. McDOWELL*

[*Read September 15, 1938.*]

The purification plant of the Biddeford and Saco Water Co. is located in Biddeford, Maine, on the west bank of the Saco River about two and one half miles up stream from the center of the city. It serves the cities of Biddeford and Saco, the town of Old Orchard Beach, and a portion of the town of Scarboro known as Grand Beach and Pine Point. The winter population of these areas is about 27,000 and is fairly constant, but the summer population fluctuates widely and at times is estimated to be as high as 60,000. This condition of course creates a fluctuating demand with a rather high peak load during the summer months, especially during periods of hot, dry weather. As the storage facilities are limited, the plant must be of such size as to take care of these peak loads, and it is consequently not operated to capacity during the winter months.

Previous to 1935, the plant consisted of 22 units of wooden, tub-type filters having a total capacity of 4½ m.g.d., a small settling basin, and a clear well. About ten years ago it became evident that before many years, the capacity would have to be increased, and in 1934, an unusually dry, hot season, the demand came very close to our total capacity. The age and condition of the old plant, together with the recent changes in the art of water purification made it impractical to enlarge the old facilities, and the management decided to build a new and modern plant. Over a period of several years numerous experiments had been carried on to determine the grade of sand, method and time of coagulation, and other chemical treatments best adapted for the purification of Saco River water, and the finished design had incorporated in it the results of these experiments and of many years of experience in the treatment of this water.

The finished plans were drawn by the firm of Burgess & Niple of Columbus, Ohio, and after several revisions they were in final shape and ready for the start of contruction early in 1935. The construction of the plant was under the personal supervision of a mem-

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ber of the designing firm and was carried on entirely by our own organization with the exception of a few minor details.

The construction of the sedimentation basin was completed late in 1935. This is a square, reinforced-concrete structure, open at the top, with a red brick super-structure above. It has a capacity of 1,2 m.g. and is divided longitudinally by a concrete wall into two basins of equal size which may be operated separately or in parallel. At the present rate of pumping it provides a retention period of about five hours. At the influent end of each basin is a series of over-and-under baffles which provide about a fifteen-minute period of agitation to the incoming water. Each basin is divided into two bays by a brick baffle wall so arranged that the water in passing through is obliged to travel the length of the basin twice. The baffle is located off the center line so that the velocity of the flow in the second, or return, bay is greatly reduced before the clarified water reaches the outlet. The housed open type of basin which, I believe, is rather unusual in this section of the country was adopted in order to enable the operators to study its action at all times, so that necessary adjustments in rate of flow and chemical dosage could be made quickly when required. It also prevents the formation of ice which caused some difficulty in the old plant as the buildings are in a very exposed location where the prevailing north wind has a clear sweep of several miles along the course of the Saco River. The temperature in the basin is maintained above freezing at all times by means of steam heaters. During the winter of 1935-36 the new basin was operated in conjunction with the old filters and the old basin was abandoned. Plans were drawn and preparations made for the construction of the new filters during the following summer of 1936. See Figure 1.

In March, 1936, as many of you have good cause to remember, most of New England was visited by a disastrous flood, and the Saco River valley was one of the places so favored. The waters of the Saco River rose to a point far in excess of any known previous level, and for about a week our old filter plant and the pumping station which adjoins it were submerged. At the peak of the flood the water reached a depth of seven feet above the engine-room floor; filters and all machinery were entirely submerged, and for ten days all operations were suspended. The new basin which, fortunately, had been built at a higher elevation than the old structures, escaped injury. During the flood, river water of rather indifferent quality was supplied to the distribution system by emergency pumps at several large industrial plants within the city.

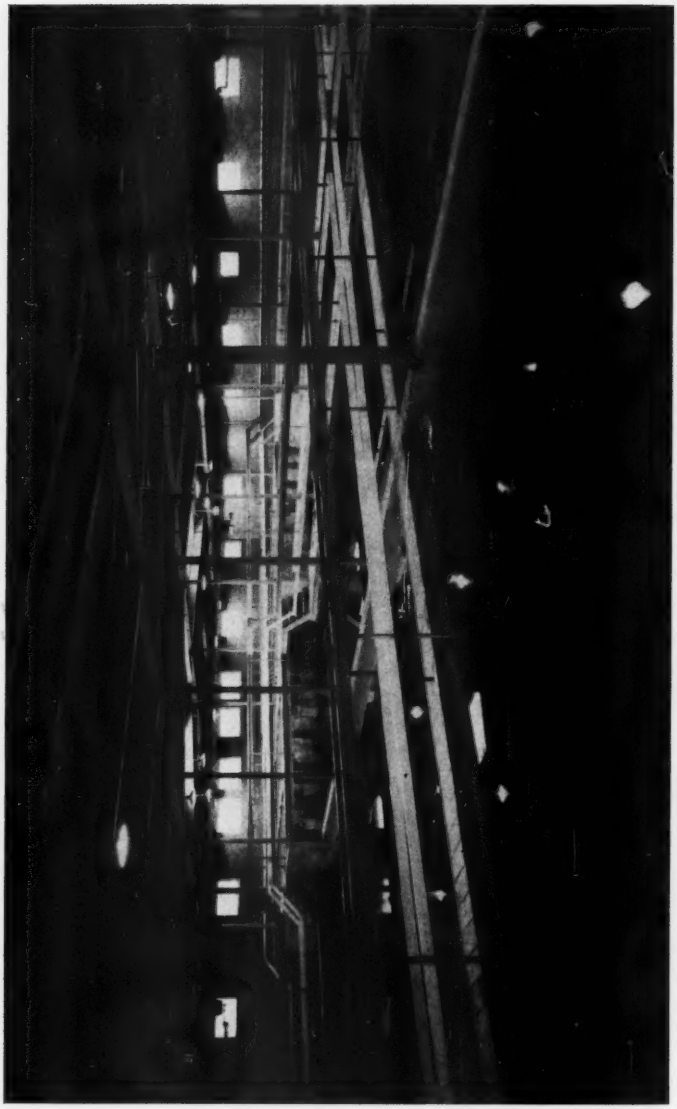

FIG. 1—SEDIMENTATION BASIN, BIDDEFORD, ME.

Fig. 1—Sedimentation Basin, Biddeford, Me.

Although it is extremely improbable that we will ever again experience a flood of equal magnitude, this demonstration of what the Saco River really can do compelled us to make many changes in the design of the new filter plant and entirely to revamp our pumping station. With this end in view, previous plans were abandoned and an entirely new set of plans prepared. As finally constructed, the filter plant and pumping station equipment are entirely enclosed by heavily reinforced, water tight, concrete walls which are carried to an elevation several feet above the peak of the March, 1936, flood. The electric substation was moved to higher ground; all underground wiring was removed and is now carried at an elevation where it cannot be reached by flood water.

As soon as the débris had been cleared away and the damage incident to the flood repaired, work was resumed on the new filter plant and pumping station and these were completed in the summer of 1937.

The filter plant is a reinforced concrete structure with brick superstructure and is built on pile foundations. The outside is of red brick and the inside of buff brick with California stucco ceilings of similar color. The six filter units are rectangular in shape, of the center-gullet, gravity type with concrete clear wells beneath. They are arranged in two rows of three units each, with a gallery between which contains the piping and operating apparatus. Each unit is equipped with Venturi controllers, quick-opening, hydraulically operated valves, loss of head and rate of flow gauges, and control tables. At the conventional rate of 125 m.g.a.d. the capacity is about 8 m.g.d. See Figure 2.

The underdrain system is made of 2½-in. copper tubes with 5/16-in. holes drilled in the bottom, and a layer of coarse crushed trap rock. The copper tubes are all connected to a common concrete conduit located at the center of the filter unit and running at right angles to the pipe gallery. Above the layer of trap rock is a layer of gravel 15½-in. thick ranging in size from ¾ to 1/10-in. The filtering medium is composed of a 3-in. layer of torpedo sand and 30 in. of Cape May filter sand having an effective size of 0.48 mm. and a uniformity coefficient of 1.35. The wash-water troughs are of special design and were fabricated of copper-bearing steel by the Portland Co. The troughs are connected directly to a concrete conduit which is immediately above and parallel to the clear-water conduit. The wash water is carried by a 24-in. cast-iron sewer to the river at a point below the intake.

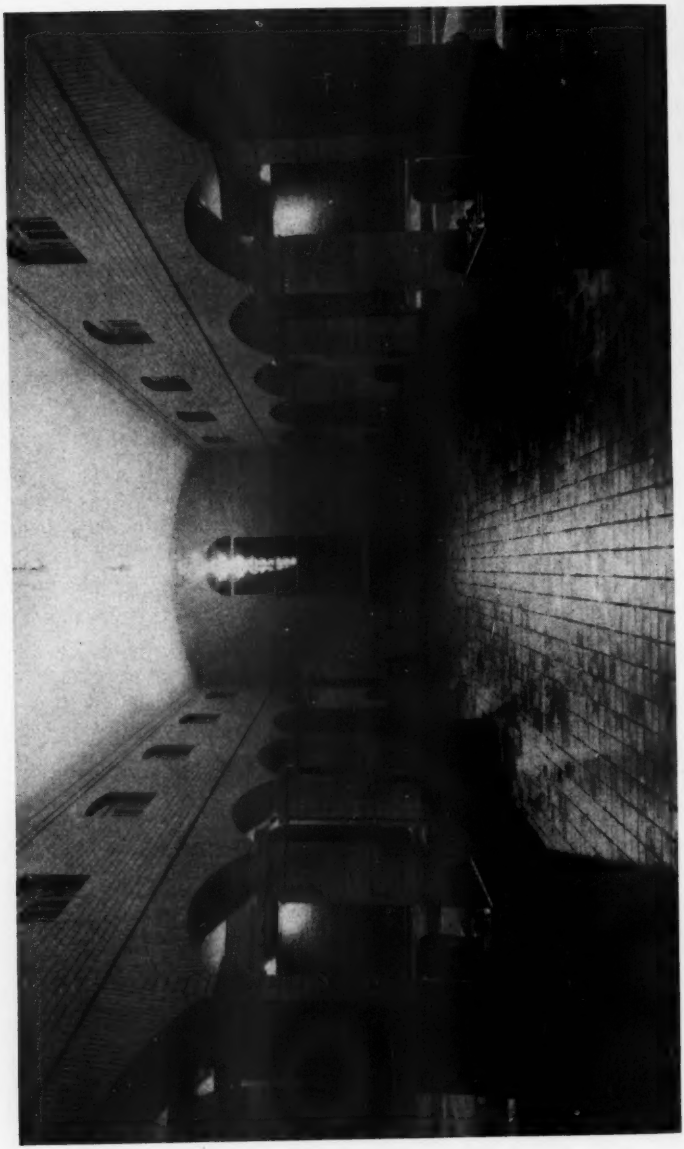

FIG. 2.—FILTER OPERATING GALLERY, BIDDEFORD, ME.

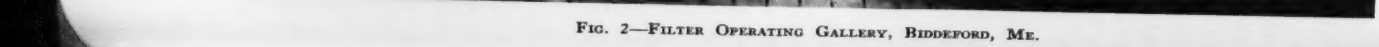

FIG. 2—FILTER OPERATING GALLERY, BIDDEFORD, ME.

SUMMARY OF OPERATIONS FIRST EIGHT MONTHS OF 1938

1938 Month	Pumpage m.g.	Wash m.g.	Water %	Av. Filter Runs Hrs.	Final Loss of Head	Alum g.p.g.	Soda Ash g.p.g.	Chlorine p.p.m.	Color R	Color F	Turbidity R	Turbidity F	pH R	pH F	Alkalinity R	Alkalinity F	Hardness R	Hardness F	Bacteria per c.c. 48 hr. Raw	Bacteria per c.c. 37° c. Basin	Bacteria per c.c. 37° c. Clear Well	Conf'md *B. coli* Final Eff.	Conf'md *B. coli* Final Eff.
Jan.	66.61	1.32	1.98	37.6	6	0.82	1.0	0.64	64	2.5			6.5	7.1	4.9	15.6	9.4	9.8	160	38	65	1.0	0
Feb.	56.84	1.09	1.92	41.3	6	0.90	1.14	0.60	43	0			6.5	7.1	4.2	17.7	9.3	10.7	70	21	4	1.0	0
Mar.	64.81	1.32	2.04	40.0	6	0.72	1.04	0.50	42	0			6.6	7.3	5.2	19.0	8.8	10.9	70	28	6	0.77	0
Apr.	60.27	1.50	2.49	30.8	6	0.65	0.84	0.58	40	0	11.3	0	6.7	7.3	3.6	14.8	7.2	8.3	43	20	4	1.33	0
May	61.45	1.31	2.14	36.1	6	0.76	0.81	0.58	46	0	8.6	0	6.9	7.3	4.9	13.7	6.3	7.5	40	15	6	1.03	0
June	63.31	1.16	1.83	36.8	6	0.81	0.90	0.71	44	0	4.6	0	6.9	7.2	6.8	15.6	7.4	8.9	68	30	21	1.16	0
July	86.63	1.36	1.57	38.0	6	1.04	1.04	0.67	52	0	7.7	0	6.9	7.1	7.8	17.6	7.46	8.76	119	39	17.6	2.2	0
Aug.	91.49	1.54	1.69	40.6	6	1.29	1.18	0.75	48	0.58	3.9	0	6.9	7.2	7.5	17.0	6.60	7.60	143*	52*	13.1*	0.42*	0
Average	68.93	1.33	1.96	37.6	6	0.87	0.99	0.63	47.4	0.38	7.2	0	6.7	7.2	5.6	16.4	7.8	9.1	89.1	30.4	17.1	1.11	0

R=raw-water.

F=filtered water.

*24 hr.

One unique feature of the plant is the fact that none of the water-retaining walls are exposed to the outside air. The concrete walls of the substructure which support the building above are separate and removed from the walls of the filters and clear-wells by an 8-in. air space. While this added something to the cost of the project, we believe it will obviate the difficulty caused by seepage and consequent ice formation and disintegration of concrete that may be observed on many structures in this climate where water-retaining concrete walls are exposed to the weather.

As far as operation is concerned, it follows very closely the conventional procedure in plants of this type with which we are all familiar. Water is drawn from the river through an intake chamber containing movable screens and is forced by the low-lift pumps through a 20-in. main to one end of the sedimentation basin. Alum is introduced at the suction of the low-lift pumps and passes through the pumps with the raw water. The mixture enters the basin at one end at the bottom, and is forced rapidly through a series of over-and-under baffles to insure a thorough mixing and the formation of a suitable floc. It then traverses the first bay of the basin, reverses its direction of flow, and returns via the second bay, where the upper, clearer layers are skimmed off by means of a concrete weir and conducted through a 36-in. pipe to the filters. Accumulated sediment in the bottom of the basin is removed periodically by means of suitable sludge valves connected to the sewer. After passing through the filters, the effluent travels slowly through a series of three clear wells where soda ash is added for pH correction. As the water leaves the clear wells, liquid chlorine is added, and the finished water is pumped directly to the reservoir and distribution system.

Filter washing is accomplished by means of a violent backwash of filtered water only, and no air or mechanical means of agitation is employed. Wash water is supplied from an elevated steel tank of 75,000-gal. capacity. The tank is refilled automatically by a small centrifugal pump which is located in the pipe gallery and which takes its suction directly from the clear wells.

At the present time, we are operating the filters with a maximum loss of head of 6 ft. Under these conditions the filter runs average about 35 to 40 hours in length and the wash water requirements are slightly under 2% of the filter output.

Both the pumping station and purification plant are operated electrically by power supplied over a private high-tension line direct from the power company about 3 miles distant. All power units

however, have either steam or gasoline-driven stand-bys so that the entire plant could be operated if the supply of electric power should fail.

The water of the Saco River, from which the supply is taken, presents no unusual problems in purification. The stream has its source in the White Mountains of New Hampshire, and flows through forest and farm land with no large towns or industrial centers and consequently few sources of pollution. It has numerous rapids and dams along its course which act more or less as natural aerators. A typical analysis of this water in p.p.m. would be somewhat as follows: Alkalinity 5.1; turbidity, 8; color, 47; pH, 6.8; hardness, 7.5; bacteria per c.c., 75. From these figures it will be noted that the water is very soft, and low in alkalinity. The turbidity is also low except during short periods immediately following severe storms, when it occasionally increases to 70 p.p.m. Tastes and odors are practically negligible and bacteria counts are relatively low, although *B.coli* are found in most samples. The color however is rather high and the low pH makes this water, like most of the waters in this section of New England, quite corrosive. The principal problem therefore is the removal of color and bacteria and the control of the corrosive activity of the effluent.

With the exception of pH control, the new plant has been very successful. Turbidity of the effluent has been maintained below 5 p.p.m. at all times, and during most of the time it has been practically zero. Color has been entirely absent. Bacteria counts in the finished water have averaged about 1.05 per c.c. and the presence of *B.coli* has never been detected. In this connection, the action of the new sedimentation basin is especially interesting, as it has effected a reduction of over 66% in the bacteria count before filtration.

Control of pH of the finished water by the use of soda ash has not been particularly successful. Experiments have demonstrated that in order to make this water non-corrosive, a pH of 8.4 to 8.5 must be maintained. This requires large doses of soda ash which, aside from adding considerably to the cost of operation, impart to the water a slight medicinal taste that is objectionable. Our experiments indicated the the pH could be raised with soda ash to about 7.5 without trouble, but when it was carried beyond this point, complaints of unpleasant tastes in the water became numerous. At the present time other methods are being considered, and a way will undoubtedly be found to control the pH and the corrosive tendencies of the water which will be more economical and not objectionable to consumers.

HISTORY OF CAST IRON PIPE

BY WILLIAM R. CONARD*

[*Read September 13, 1938.*]

The title of this paper indicates that it is to deal with one of many and varied products of iron and its companion known among the metal consumers as steel, which generally speaking is a highly refined iron.

Quoting from an encyclopedia, "iron" is described as "A hard, heavy, well known metal. Pure iron is silvery white but it is seldom seen." Quoting further: "Iron is the most useful of all metals, and of all metals it is the most widely distributed in Nature. It forms a twentieth part of the world's crust. It is essential to life of all sorts. It is found in the green chlorophyll of plants and in the blood of man and animals. It occurs in meteorites and in certain lavas and volcanic rocks. It has been ascertained that iron is present in the Sun."

It is not definitely known at what stage of primitive man iron was first put to use after having been reduced and made into forms from the original ore. This is so because articles made of iron have been found together with other prehistoric things and in conjunction with articles made of other ores, such as copper, lead, and zinc, and with articles made of stone.

The earliest recorded mention of iron is in the Old Testament in Genesis, where Tubal-cain is referred to as "an instructor of every artificer in brass and iron."

At what time iron was first made in the form of pipe is not definitely known, the earliest records indicating that it was about 1660 A.D. when work on the pipe line at Versailles, France was begun. From then until about 1738, when coke as a reducing agent came into use, there appears little mention of pipe made of cast iron.

Since writing the foregoing paragraph the writer has reviewed a translation of a recent German publication, *Einst-Jetzel* (Then to Now), in which the author says: "It was in the second half of the 15th Century that the first iron pipes were cast in the Seigen Country. This was done in a primitive way. A century later, men had progressed so far that they used closed form-boxes called molds. The pipes were cast in these molds as they lay in the sand. This prac-

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tice is easily recognized by the seams running the length of the pipe. Only short pipes could be manufactured, and it was not possible to prevent a bending of the core. This caused an uneven thickness of the walls often found in old pipes. Casting was difficult and necessitated much time. Thus read the chronicles of a pipe factory in Altenan which cast 24 to 26 pipes a week at the beginning of the 17th Century. Therefore, it is not surprising that the Metternich line at Coblenz, which is six kilometers long, took 3 years to build.

Further references in this same translation mention dates of 1455, 1562, 1582, 1684, 1701 to 1713. Also an illustration shows pipe of the "Socket and Tennon" type with the dates 1722-1760, so that these must have been the fore-runners of the bell and spigot type designed in 1785.

Many of you no doubt will recall and probably have the brochure of the Cast Iron Pipe Research Association published in 1934 which in addition to mentioning and illustrating early cast-iron pipe in this country also cites instances of its use in both England and Germany as well as France.

The first use of cast-iron pipe in this country appears to have been around 1800, in connection with the water system of Philadelphia, in which pipe imported from England was employed. The Manhattan Company of New York and the Gas System in Baltimore were also early users of cast-iron pipe.

From what we see and hear, the United States is considered by many nations still as an infant; yet out of 43 cities, there are 12 for which records show that they have used and are still using cast-iron pipe that has been in service around 100 years either for water or gas supply.

Production of cast-iron pipe was begun in 1803 in the United States, the first plant being at Millville, New Jersey and manufacture spreading thence to other parts of that state and to Eastern Pennsylvania, New York, Virginia, Ohio, Kentucky, Tennessee, Alabama, Missouri, Wisconsin, Texas, Colorado, Oregon and Utah. Kentucky, Missouri, Wisconsin and Oregon have of late years ceased to be points of production of cast-iron pipe.

In the beginning, pipe were cast in horizontal molds and in comparatively short lengths; later, casting in vertical molds of greater lengths was adopted for so-called pressure pipe, and this system prevails today for the "pit-cast" pipe, whereas pipe made by centrifugal methods has gone back to horizontal casting.

In the early days, sand compacted around a pattern gave shape

to the outer surface, and sand compacted to the outside of a form, thereby making a core, molded the inside of the pipe. This manner of casting prevailed from the beginning to within the last 20 years, when the deLavaud and Sand-spun methods of manufacture were perfected so as to make them commercially practical and the centrifugal process became a reality. Pipe is made up to 20 ft. in length.

Pipes were made almost entirely by hand in the early days; rather crude mechanical methods being the next step; then, with the advent of the traveling bridge crane and mechanical methods of making molds, together with improvements in the making of cores and along with revolving pits, pipe making became more or less a mechanical process. However, these methods resulted in increased production rather than a lessening of the number of employees. This still holds true to a greater or less extent even where pipe is made by centrifugal processes.

Back in the early days the methods used for drying molds and cores varied considerably. To a certain extent they were hit or miss, the result being a rather large proportion of imperfect pipe. As time progressed, procedure was brought under better control, and today the amount of culling necessary has been reduced considerably, with an all around improved product.

Previous to 1902 when this Association adopted standards for both pipe and fittings, there was no general standard, the larger cities in the United States each having their own particular standard and the smaller cities selecting the standards of the larger, that appeared best suited to their needs. Since the New England Standard came out in 1902, the American Society for Testing Materials and the American Water Works Association have adopted standards as well as the American Gas Association, and there is now in process of formulation the American Standard of which this Association is one of the sponsors. When finally adopted and put into use this standard will be known as Standard A 21 of the American Standards Association.

Twenty years ago, the capacity production of cast-iron pipe in the United States was between seven and eight hundred thousand tons per year. Today if the consumption demand warranted, there could be produced easily double that amount of pipe and fittings.

While history does not yet record the full life period of different materials of which pipes or conduits for carrying water are a part, it is an undisputed fact that as a popular conductor of water, both for supply and distribution, outside of buildings, cast-iron pipe shows the longest continuous period of use. As it is still by far the most

largely used, it is doubtful whether the record established will ever be exceeded by any other material.

The first known pipes of cast iron are those at Versailles, France, which are of short length cast horizontally with flanged joints. Just when the bell and spigot type of joint came into use we do not know, but it must have been during the period between the installation of pipe at Versailles and the beginning of pipe manufacture in England, for from the best information I can obtain, pipe cast in England has from the beginning been of the bell and spigot type generally speaking. Manufacture of pipe in England was begun about 1740 in the Middleborough District, and records show that cast-iron pipe was first laid in 1746 and, like the Versailles pipe, had flanged joints. About 40 years after this time a man by the name of Thomas Simpson invented the bell and spigot joint, and from that time up to the present the bell and spigot type of pipe has been by far the most widely used for the purpose for carrying water from one point to another.

While the form of the bells and spigots may have been different, pipe has from the beginning of manufacture at Millville, N. J. been of bell and spigot type in this country, for general purposes. It is true that various types of joints have been designed and used from time to time; these, however, have usually been for some special purpose or condition.

Flanged joints are probably the oldest type of mechanical joint, with sleeve joints of the Dresser type next. Of recent years quite a variety of mechanical joints, some a combination of bell and spigot with couplings, some wholely mechanical, has been designed.

For completing the bell and spigot joint lead has the longest history, with compounds, wood and cement following along.

Cast-iron pipe is used for a variety of purposes, although its greatest use is in connection with water supply. It is also used in connection with gas supply, in buildings, in manufacturing processes, road building, railroad and other industries, also in sewerage and sewage disposal works, some types of steam service, and other miscellaneous services.

In the water works industry, the lightest service is in connection with water purification plants where pressures are light, and there is usually very little, if any, exterior loading. The heaviest service is probably for high-pressure fire systems, where the pressures run high and the exterior loading is often heavy.

As to the future of cast-iron pipe, who can say. It has been

shown to have had an effective life of as much as 500 years. Its use is normally trouble free. If properly protected, its carrying capacity is maintained. Its cost, all things considered, is within reason. Its producers have, at least within recent years, endeavored to meet new requirements as they have arisen. From time to time, new uses have been found for it. Normal consumption of cast-iron pipe is in line with the general business activity of our country.

It may also be said that from an engineering standpoint the general use of cast-iron pipe for water works purposes is holding its place at the head of the list of materials used, and that in evaluating water works as a utility it represents the largest capital investment in the field. Further, due to its long effective life at reasonable cost per unit of value, it presents a dependable constant for use in the appraisal of values whether public or private.

CONTROLLING TASTES AND ODORS IN RESERVOIRS OF THE NEW HAVEN WATER COMPANY

BY MARSHALL S. WELLINGTON*

[*Read September 24, 1937.*]

In the years 1928 and 1929, tastes and odors in the supplies of the New Haven Water Company made it desirable to find a method by which they would either be eliminated or greatly reduced. After serious consideration, it was thought that if a means to give a check on the organisms could be found, so that their growth could be stopped before their concentration reached a dangerous point, we could overcome the taste and odor problem.

The procedure that we have developed has been so successful that, since we started it in 1930, there have been only five times that tastes and odors have occurred in our reservoirs. One of these times was due to a wrong interpretation of the chart. Another was due to the fact that an order to a foreman to add copper sulphate miscarried. As to the other three times, they are still with us and seem to be due to the algae growing in the supply mains more than in a reservoir. We feel this is a pretty good record considering the number of reservoirs that we have.

The New Haven Water Company has eleven reservoirs in service at all times. Nine of these are used to furnish water directly to the distribution mains, while the other two are storage reservoirs that flow into some of the supply reservoirs. If these storage reservoirs have algae in them, it is possible for them to seed the supply reservoirs. With all these reservoirs to protect from taste and odor, the method used must be simple, yet effective. After a year and a half of experiment we found that the analysis of a weekly sample taken near the intake gatehouse at approximately the same level that the water was being drawn, gave sufficiently accurate results. If ice conditions interfered with this sampling point, water running over the spillway was used for analysis. At times when every place was frozen, holes were cut in the ice near the intake gatehouse and samples collected through them. Some winters there has been so much ice on the reservoirs that holes were cut through eighteen inches of ice.

The samples are collected in 500-ml., narrow-mouth Pyrex bot-

*Sanitary Engineer and Superintendent of Chlorination, New Haven Water Company, New Haven, Conn.

tles and taken immediately to the laboratory where they are analysed by the methods suggested in "Standard Methods of Water Analysis". When cold water or other conditions cause the sample to filter very slowly the process may be speeded up by attaching a piece of rubber tubing to the glass tube in the stopper at the bottom of the filter and dropping this piece of hose to the floor. This set up of the apparatus allows about a four-foot negative head to be placed on the filter funnel. This negative head speeds the rate of filtration. The aspirator can be used for the same purpose but is not so convenient, and its action may be so violent that it will break up the microörganisms.

With eleven reservoirs to check we cannot consider every type of microörganisms that we find. Only the types that in our experience cause taste and odor in our reservoirs are accurately tabulated. These consist of six kinds: *Asterionella, Tabellaria, Dinobryon, Uroglena, Synura* and *Anabaena*. If there are any other microörganisms present in large numbers, a record is made of them for further reference. A taste and odor developing, and none of the regular six microörganisms being present, the trouble is probably caused by a type of algae present in large numbers and previously recorded. Also a notation is made of any unusual types found. We only use the six mentioned for our records in general practice.

From our records of the microörganisms present in the last eight years a general conclusion as to the time when they can be found, can be drawn. *Asterionella* and *Tabellaria* are generally found from November to April, *Dinobryon* in May and June, and again in September and October. *Synura* and *Uroglena* follow *Dinobryon* in the spring and precede it in the fall. July and August are free from the six types of algae that we are interested in. Every rule has an exception; in our case this is Prospect Reservoir. This reservoir usually has its growth of *Dinobryon, Uroglena*, and *Synura* in the summer months of July, August, and September. No *Asterionella* or *Tabellaria* are found in this reservoir. This reservoir will be spoken about later.

The method of keeping records of the number of microörganisms needed some experimenting before a satisfactory one was developed. The result of this experiment was the adoption of a chart. This chart is drawn on semi-logarithmic paper with a three cycle vertical scale and a daily horizontal scale. The number of standard areal units of the microörganism is plotted on the vertical scale against the day on the horizontal scale. This method of plotting makes it possible to have a continuous line graph for an entire year of each type of microörganism present in the reservoir. As we use the charts, the

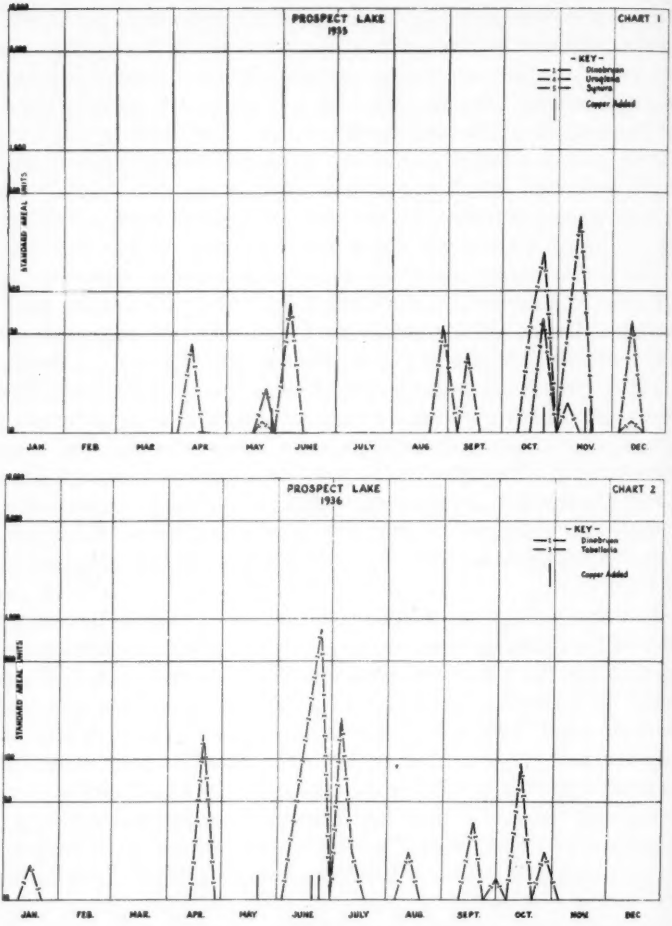
different microörganisms are shown by different colored lines. These are easier to draw and easier to follow than black lines made of different symbols. The days that copper sulphate is added are shown by a short vertical line. As each reservoir requires a different amount of copper sulphate and the amount is always the same for each reservoir, the line showing the addition of copper sulphate is not drawn to scale, as in our case it would be too confusing. If one lake or part of it was being controlled by varying amounts of copper sulphate a scale for the amount being added would be useful.

There are many places on these charts where it appears that the number of microörganism is decreasing before the copper sulphate is added. There are two reasons for this. First the copper sulphate is not added on the same day as the sample is taken. Second the method of constructing the graph. The lag in time for the addition of the copper sulphate is due to the fact that results of the analysis of the sample of water collected in the morning is not known until early afternoon. Enough time to treat the reservoir is then not available. The entire amount of copper sulphate to treat the reservoir must be added as nearly as possible at one time. The condition of the weather has to be considered as it is necessary to go out on the reservoir in a boat.

In constructing the graph a straight line is drawn between two points. This causes a downward trend to the line at once, where in all probability the microörganisms are still as numerous or at the same increase until the copper sulphate is added. It would be more accurate either to extend the graph at the same slope or to draw it horizontal to the day that copper sulphate is added. This is a refinement that I believe is unnecessary for the purpose that the charts serve.

A sharp rise of the lines on the chart indicates that the algae are increasing very rapidly and may suddenly reach the point where they will cause taste and odors. When much of an increase occurs we immediately treat with copper sulphate. A slow rise in the lines indicates that the algae are present and should be watched. After several weeks, if the lines are still steadily but slowly increasing, the reservoir is treated with copper sulphate. When *Dinobryon* sheaths appear, it seems to indicate that this microörganism is dying.

Charts 1 and 2 show the variation of growth in Prospect Reservoir for the years 1935 and 1936. This reservoir has a capacity of 10 m.g. and a maximum depth of 10 ft. with an average depth of 5 ft. A road crosses the upper end of the reservoir, forming a small body of water about one-third the surface area of the reservoir, and with

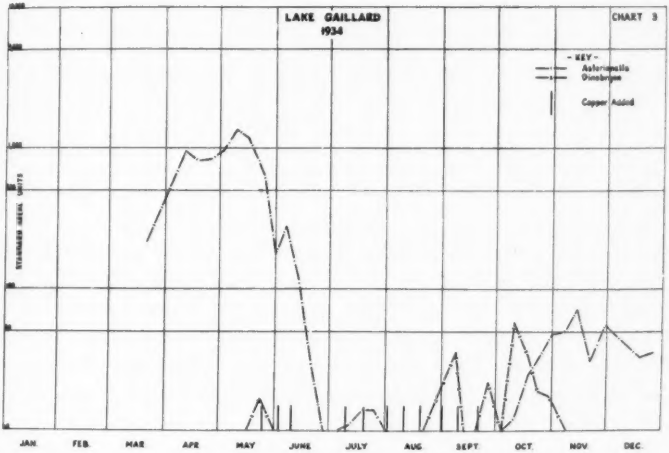


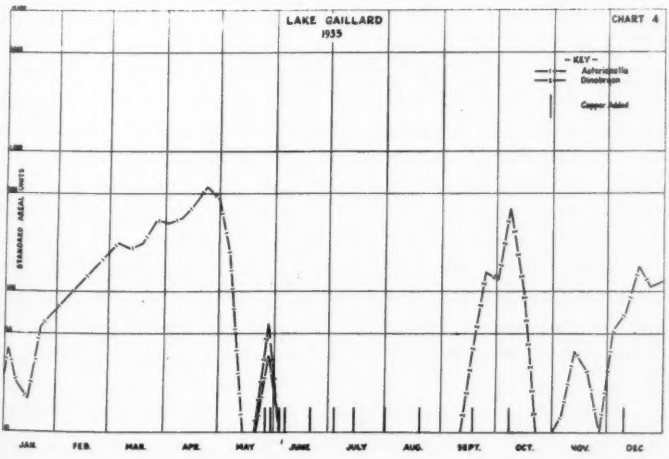
an average depth of 4 ft. This small part of the reservoir is connected to the larger by a culvert under the road. Most of the water supplying the reservoir enters it through this smaller pond.

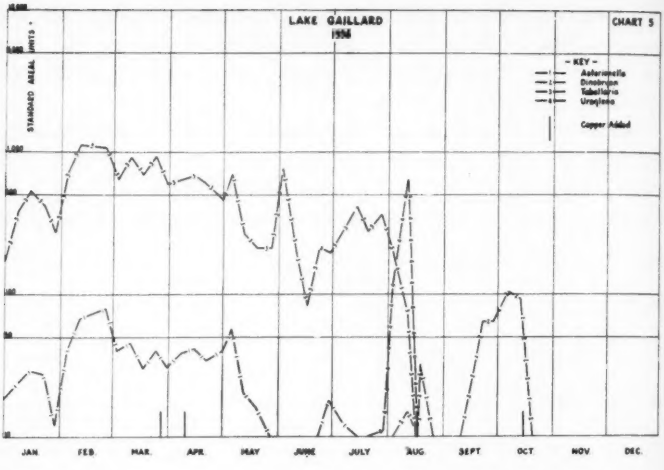
On Chart 1, at the end of May and the first of November, and on Chart 2, at the beginning of July, the graph line touches zero after an application of copper sulphate and then immediately climbs again. This second increase is caused by the fact that the smaller portion of the reservoir had not been treated and reseeded the larger. The

practice now is to treat both the smaller and larger parts. On Chart 1, at the middle of November, the organisms appear on the decline before the addition of copper. The explanation for this has been given in a previous paragraph of this paper.

Charts 3, 4 and 5 show the variation of the microörganism in Lake Gaillard. Lake Gaillard has a capacity of 15,642 m.g. with a maximum depth of 100 ft. and a water surface area of 1,115.2 acres. In Charts 3 and 4 *Asterionella* is shown while on Chart 5 both



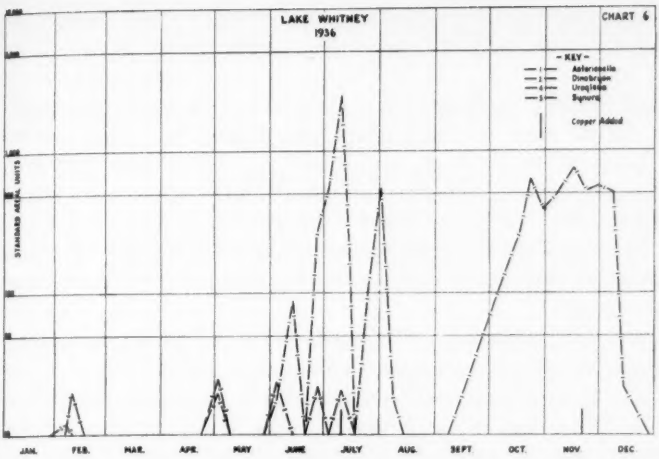




Asterionella and *Tabellaria* are shown. This difference occurs as it was not until late in the year 1935 that it was found that some of the organisms that had been listed as *Asterionella* were in reality *Tabellaria*. Chart 4, at the first of December, and Chart 5, at the last of March and first of April, show that copper was added without any reduction in number of organisms. The reason for the failure of the copper to take effect is probably due to the water being so cold. Charts 4 and 5 show copper added at frequent intervals. This copper was added in small quantities around the edge of the reservoir and in shallow spots.

Chart 6 shows the organisms present in the lower or intake end of Lake Whitney, a large lake, the upper reaches of which are very shallow and rank with algae of all kinds. The copper for this lake is added by hanging bags of it from a highway bridge near the lower end.

The amount of copper sulphate added to the reservoirs to kill the algae is two pounds per million gallons of water. The amount of water is considered as the total capacity of the reservoir with exception of Lake Gaillard, where the top fifteen feet only are considered. The copper sulphate is added by dragging it in bags over the sides of a boat. They are row boats, row boats with outboard motors, and launches. At times, to keep a lower reservoir from becoming seeded from a higher one, a bag containing copper sulphate is suspended in the spillway of the higher reservoir.



We have found no method by which tastes and odors occurring when there is ice on the reservoir or the water is too cold efficiently to dissolve the copper sulphate can be controlled. We have some hopes from the chlorine-ammonia treatment. All that can be done when ice and algae occur together is to be patient and do your best to pacify the customers. It helps considerably to admit that the taste is there, that you knew it before the complaint came, and that everything possible is being done to overcome it.

There are many ways in which the foregoing facts are inaccurate from a scientific viewpoint, but bear in mind that a rapid means of determining and evaluating the microörganisms and thus controlling them so as to eliminate the tastes and odors that they cause, is what is sought.

No attempt has been made to determine the concentration of the various microörganisms that will cause taste and odor. It has been found that under our conditions a thousand units of *Asterionella* or *Tabellaria,* either singly or in combination will give a taste and odor. It has been found on several occasions that, with this count in the supply, the count in the distribution mains has been as high as two thousand or more. No method has yet been found of reducing this great number in the mains. It would appear from experience to date that the taste and odor can be improved by using a proper amount of ammonia along with chlorine. What the required dose of chlorine and the ammonia ratio on this supply are we are not able to say at the present time.

STANDBY EMERGENCY POWER EQUIPMENT FOR PUMPING STATIONS

BY CHARLES E. GREENE*

[*Read November 17, 1938.*]

In selecting a standby power supply for a pumping plant, we try to select one that is immune to the hazards that affect the normal power supply.

Electrical Equipment. A majority of the plants occupying the attention of this Association have electric power for their normal energy. Another source of electric power is, therefore, the first means considered for standby purposes, because it is usually less expensive to install and requires less space. It is simpler to connect all the pumps to another electric supply from outside the plant than to get pumps going that are operated by an entirely different means.

In evaluating the dependability of an electric power supply under emergency conditions we try to foresee all the hazards to the normal supply and make the standby power supply as immune to them as possible.

Starting inside the plant itself we need separate oil switches for the standby power and often separate buses in the switchboard. Neither of these items is prohibitively expensive, but their cost cannot be neglected. The care with which the switchboard and electrical connections are laid out for transferring affect the reliability and convenience of both the normal and standby power systems. Wherever electric lines from different sources come together in a switchboard, considerable care must be used to prevent troublesome or dangerous connections being made. Common forms of protection required on standby power lines are:

1. Overcurrent or electrical fault-protection (short circuit or ground)—usually the same as required in the normal supply.
2. Phase-rotation protection—that is to be sure that the motors will rotate in the correct direction.
3. Reverse-power protection—that is against power flowing to the plant on one line and away from the plant on the other toward a fault outside the plant.

*Consulting Engineer, Boston, Mass.

4. Synchronism indication—which prevents connecting two lines together in the plant from sources that may not be in synchronism.

The latter two can be omitted if the standby power is never used except after the normal source has failed or been cut off. The result of this economy is that the whole plant has to be dead and completely dark before the changeover is made. Consequently, the standby source is not frequently used and when needed may be found to be unavailable or unusable in a way that would have been discovered if the layout had permitted changing from one source to the other more conveniently.

Outside the plant we try to be sure that the standby power is brought to the plant in a way that is immune to the hazards that affect the normal source. For instance, if one line is overhead and exposed to sleet, ice, high winds, or falling trees, we try to have the alternate source underground so as to be immune to these exposures, even if it is exposed to flooding, continuous moisture, road construction, and other hazards.

Underground lines are usually more dependable, even against floods, if carefully installed. Sometimes a second overhead line may be of value if both lines follow widely separated routes, never on the same poles and not exposed to the same fire hazard area.

Going back further, we investigate the dependability of the source from which these lines are energized and consider the alternate source to be of greater value if not energized from the same substation or the same bank of transformers or not receiving its power from the same prime-movers or same generating station.

Illustrating the point we have a switchboard (Figure 1) serving six large sewage pumps of such importance that three incoming lines are provided, two from a normal source and one from a standby source. The incoming-line relay-equipment with the double buses probably accounts for 30% to 40% of the total cost of this switchboard. Each of these incoming-line panels has overcurrent protection, reverse-power protection, phase rotation, and synchronism indication so that the operators can use any and actually do use all lines frequently and can be sure of the availability of all sources.

The supplementary electric line for standby power usually works out most reliable and least expensive for large city plants that are located near power plants of considerable size and where the amount of power normally purchased is considerable.

If all the means of power supply are kept energized all the time, the dependability is greatly increased.

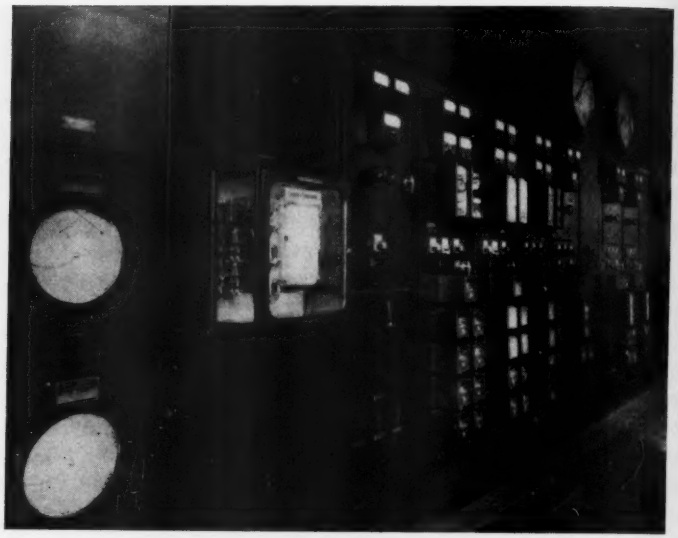


FIG. 1.—PUMPING STATION SWITCHBOARD (ROLLER-SMITH CO.), BLUE PLAINS SEWAGE TREATMENT PLANT, WASHINGTON, D. C.

The next method usually considered is to provide power generating units in the plant where the pumping is done so as to eliminate the pumping as much as possible from hazards outside the plant itself. For such a power supply we have water-power units, steam-power units, and internal-combustion-engine units. Any one of these may be alternate or standby to other types of power or to other units having similar prime movers.

Hydraulic units are omitted from this discussion as being of interest only to those who happen to have water power available at their plant locations.

Steam-Power Units. Probably no other power unit can equal the steam-power unit in dependability. We are all familiar with plants where steam pumps have been operating a great many years with an unimpeachable record for continuous service or availability. However, the cost of this type of pumping equipment and the space occupied is such that when the units need replacement or a major repair, they are replaced instead with other units of much lower first cost. They then lapse in their old age into a doubtful status as standby equipment. Veteran steam engines that are pensioned off as standby units are of considerable value when first put in reserve.

A boiler to be held in standby, as waterworks people use the term, should be either completely emptied and painted or filled full of water for protection against corrosion. This process requires time and care to lay up the plant, and considerable time and familiarity with its requirements to get it going again. In fact the time required is so great that it is impractical to put these units in commission just to see if they can be depended upon. If never used, the parts get removed, valves and piping connections get changed, the people who know how to operate the plant disappear or are replaced by people familiar only with the normally used units.

Hence the value of a steam-boiler plant and pumping unit for emergency service may be gaged by the length of time since it was last operated. I would rate such a plant as of full value the day it is laid up and of nearly full value for perhaps three to six months of idleness. After that its value diminishes until it reaches the vanishing point or becomes of very doubtful value by the end of two to three years.

First cost and space prevent this type of plant from ever being installed new for purely standby or emergency service.

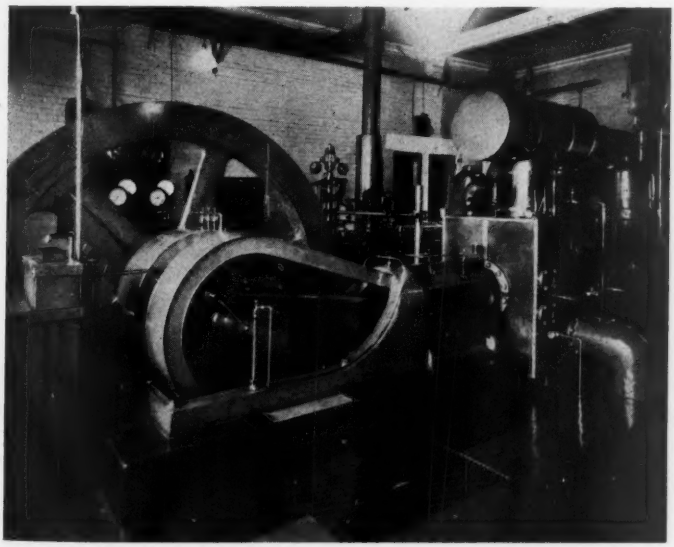


FIG. 2.—STEAM PUMPING-ENGINE (WORTHINGTON), FALMOUTH WATER DEPARTMENT, FALMOUTH, MASS.

Figure 2 shows a typical steam pumping-engine to illustrate the space required and the relative investment involved. Remember that with it is required a boiler plant requiring more space, investment and care and two to four hours hard work of several people to get going in an emergency.

This engine is not a retired veteran but is in actual daily service. It cost in the neighborhood of $40,000 and can pump about 2.5 m.g.d. right along with no perceptible wear or trouble. It does its work for a fraction of the fuel cost or electric-power cost of any competing unit.

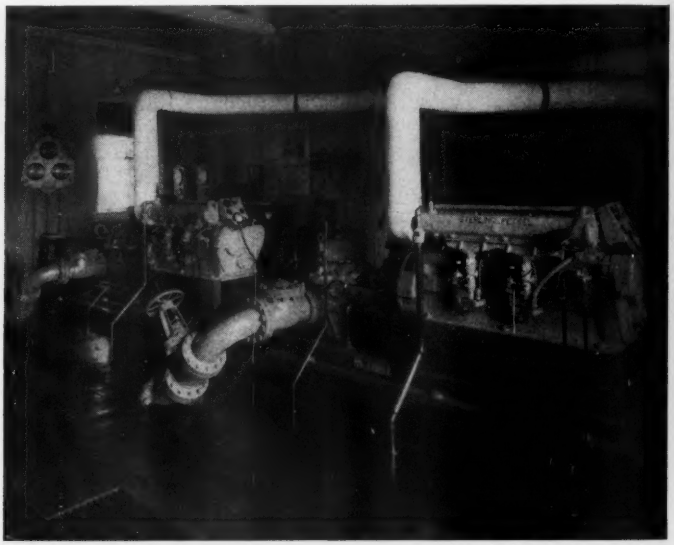


FIG. 3.—GASOLINE-ENGINE-DRIVEN, CENTRIFUGAL PUMPS (DELAVAL) (STERLING), FALMOUTH WATER WORKS, FALMOUTH, MASS.

Compare this with the type of standby unit shown in Figure 3, a pair of gasoline-engine-driven, centrifugal pumps. These two pumps together occupy one half the space of the big engine without considering the boiler and cost less than one quarter as much (under $10,000). They will pump 3.0 m.g.d. under the same conditions as the engine shown in Figure 2 and can be placed in action in five to fifteen minutes from a cold start, by one operator.

The obvious economics of the case determine that the steam en-

FIG. 4.—TYPICAL STEAM BOILER PLANT.

gine is the regular performer and the gasoline engines the standby or emergency units in this case.

Before leaving the steam-engine units, I want to show the kind of thing that happens when these plants are put in reserve. In Figure 4 we have a pair of familiar HRT boilers. To make them more convenient under modern conditions they have been equipped with oil burners. The oil burners require electric power, small to be sure, but nevertheless essential. These boilers are useless in event of electric-power failure unless one can generate the small amount of

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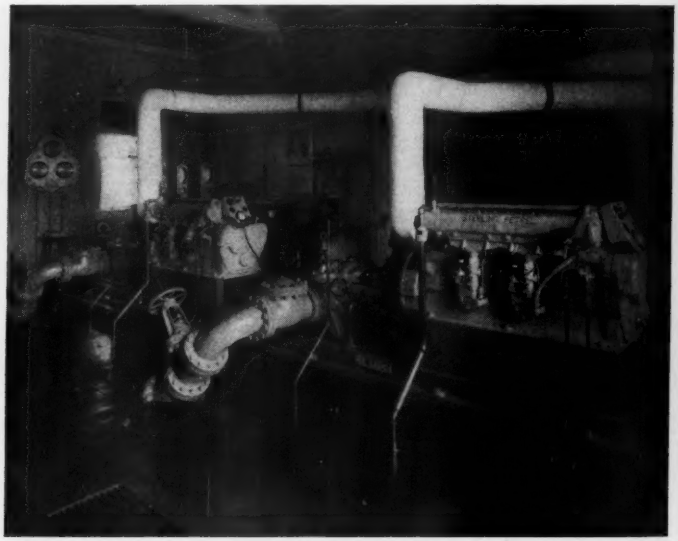

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electricity that the oil burners require independently of outside sources. This is typical of what happens to steam plants that were originally independent of outside power when they were put in reserve.

It is nearly impossible to lay out an oil-burning job that can get going in any reasonable time from a cold start without some help from another source either in the form of electricity, steam or a well sustained and very inconvenient bonfire.

Gasoline Engines. Turning to internal-combustion-engine plants, we find the gasoline-fueled engine resembling the automobile engine or motor-boat engine to be most applicable to emergency service. Its first cost is low. It is remarkably independent of outside sources of power, thanks to its kinship with auto and boat engines.

Operators are available everywhere. Engine speeds fall in the same range as centrifugal-pump speeds, thus permitting direct connection. They can be placed in operation so quickly and conveniently that they can be tested once a week or whenever there is any question as to their availability. They do require protection against freezing, a dependable means of cranking and considerable care in handling the fuel and the exhaust gases.

These engines are usually direct-connected to centrifugal pumps and are of such dimensions that they can be installed conveniently with electric-motor-driven pumps. Consequently, the stations in which we find them have numerous auxiliary units that require electricity and without which the whole plant may be nearly useless. Such equipment includes vacuum-priming pumps, heating devices, oil-burners, sump pumps, and even the station lighting system. When installing these units for emergency purposes it is vital to make a rigid canvass of the accessory equipment that the pumping operation requires. Be sure that every device necessary to the operation of the plant has a means of power supply that can operate under the emergency conditions. Small gasoline engines can be connected to vacuum pumps. Emergency working-lights can be provided from the engine storage-batteries and generator.

Some judgment must be used in estimating the amount of fuel storage to be provided for these engines in an emergency. A good rule to remember is a pint per horsepower hour. This usually results in a storage of at least 500 gal. of gasoline, and often 2,000 gal. or more. If the gasoline is not kept on hand continuously, there may be unforeseen difficulties in getting an adequate supply of fuel quickly.

In Figure 5 we see a pair of electric-motor-driven, centrifugal pumps with a gasoline-engine-driven, centrifugal standby unit. The

FIG. 5.—ELECTRIC MOTOR-DRIVEN PUMPS WITH ENGINE-DRIVEN EMERGENCY UNIT, SOUCOOK PLANT, CONCORD WATER DEPARTMENT, CONCORD, N. H.

pumps shown here have a high suction-lift, pumping from driven wells. Hence, the station has one vacuum-priming pump with a small gas engine to drive it. The heat from the engine keeps the station comfortably warm even in fairly cold weather. No doubt, it would prevent an actual freeze-up in the severest weather, at least until an emergency heating-plant could get going. However, one thing forgotten in this case was the sump pump. If any leak developed inside this plant during an electric power failure, someone would have to rig up a gasoline-engine-driven sump pump fairly soon.

I know of two stations similar to this that require electricity in connection with their sewage disposal or sanitary facilities. If there was an extended period of operation without electric power, the operators would find conditions very inconvenient or insanitary, especially since both of the stations I have in mind are surrounded by the water shed from which they pump.

Complications such as these lead to the consideration of installing gasoline-engine-driven generators for emergency-power supply. They would drive the pumps, furnish lights and all other normal services required about the plant. The electric losses in the generator and

the motor that have to come between the engine and the pump influence against electric generation, except in very small or very complicated plants.

When the requirements total up to more than about 100 hp., it is better to drive the pumps directly from the engines and, if necessary, install a small, engine-driven generator for lights and other plant purposes.

If the pump is centrifugal, the speed of a direct-connected engine can be varied to give a wide range of pump capacities, enabling the unit to meet exactly the conditions required at the time of the emergency. Sometimes, this feature enables a single unit to serve as standby for several electric-driven pumps of widely different characteristics. This appeals to me as a great advantage for the direct-connected pump.

Gasoline-engine-driven units have a very definite upper limit in size. Beyond about 200 hp., they become large and costly, because they have to operate at lower speeds. This factor also influences the selection of standby units in favor of direct-connected pumps and against electric generators because the cost of the generator also increases with the lower speeds.

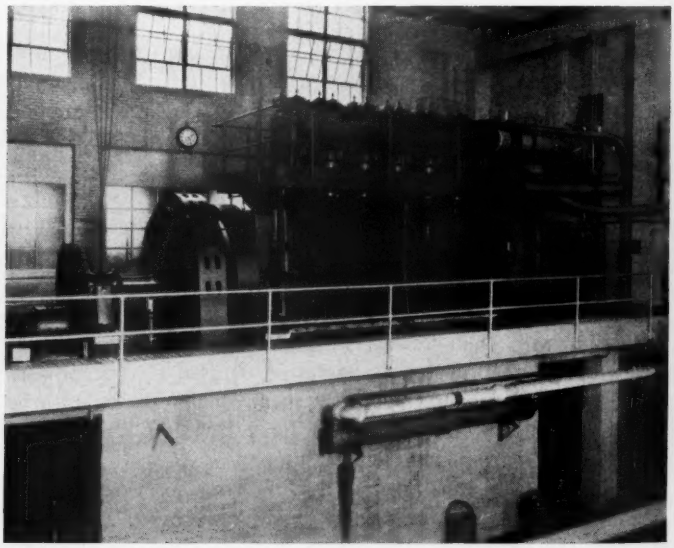

FIG. 6.—GAS-ENGINE-DRIVEN GENERATOR (RATHBURN-JONES) (ELECTRIC MACHINERY MFG. CO.), BLUE PLAINS SEWAGE TREATMENT PLANT, WASHINGTON, D. C.

To illustrate increase in cost with size of engine the 100-hp. engines shown in Figure 3 cost $1,500 each, operate at 1,800 r.p.m. while the 200-hp. engine shown in Figure 5 costs about $3,000 and runs at 1,200 r.p.m The next larger similar engine, 350 hp., costs $8,000 to $9,000 and runs at 900 r.p.m. The costs quoted are approximate and for the bare engines in each case.

Gas Engines. The engine shown in Figure 6 develops 1,200 hp., runs at 225 r.p.m. and costs about $75,000. This engine is not a gasoline engine but is practically the same, since it runs on gas with electric-spark ignition. The difference is that it has a mixing valve instead of a carburetor. In this case, the gas used is sewage gas from the sludge-digestion process. This engine operates continuously. Since last April it has had only about 15 hours of interruption to clean the distributor points and adjust the governor. Here, the usual situation is reversed and electric power is a standby for gas-engine power.

That is due to the unusual economics of the case where this engine uses an obnoxious and dangerous waste product and from it produces all the electric power the plant usually needs. The engine exhaust is used in a boiler to make steam for heating the plant. The warm engine jacket-water makes the sludge digestion process go along evenly and smoothly.

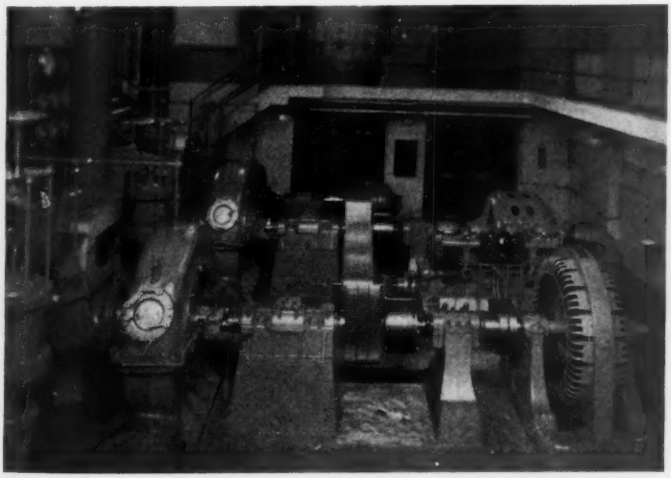

FIG. 7.—EMERGENCY GAS-ENGINE-DRIVE FOR SEWAGE PUMPS (STERLING) (MORRIS MACHINE WORKS), KLINES ISLAND SEWAGE TREATMENT PLANT, ALLENTOWN, PA.

Another instance of gas being used instead of gasoline for standby power is shown in Figure 7. This of interest because the engine is placed between two pumps and can drive either pump by a chain drive that can be changed from one pump to the other. This is *poor* engineering but it *works* very well.

FIG. 8.—DIESEL-ENGINE-DRIVEN PUMP (WORTHINGTON), PENNICHUCK WATER CO., NASHUA, N. H.

Diesel Engines. Diesel engines should receive some consideration as standby power but usually cannot compete with the gasoline engine, unless there is some other consideration than emergency. They operate at slower speeds, usually preventing direct connection. However, their fuel economy, simplicity, and reliability are much to be preferred. For purposes of comparison, the unit shown in Figure 8 is roughly comparable in capacity (at 250 hp.) to the 200-hp. engine unit that was shown before, and the two units usually pump about the same amount of water. The Diesel unit, including the gear and accessories, costs three to four times as much as the gas-engine unit. On the other hand, the Diesel can operate for one quarter of the fuel cost and can carry its load day by day with very little upkeep and maintenance, whereas the gas-engine unit is only fit for intermittent service or a relatively short life on continuous duty.

A Diesel unit has standby value in connection with electric, steam, or water power units on the same system by being immune to many conditions that affect the other units. Usually, its purchase cannot be justified on emergency considerations alone.

Portable Units. Portable, engine-driven, electric, generating sets were found to be useful in general emergency service during the recent New England hurricane and flood. Most of these units generate direct current which is usable for lighting but seldom useful for pumping service. These units usually are limited to 15- to 25-kw. capacity, suitable for electric-welding service and for lighting of county fairs, outdoor performances and festivals. Whether one of these units happens to be available, depends on the conditions at the moment when the emergency occurs.

Operators who would be helped by units of this size would do well to check up where such units can be obtained in their territory, from time to time.

A portable engine-unit would look like the unit shown in Figure 9, mounted on an automobile truck with a simple control board and some sort of more or less weatherproof housing.

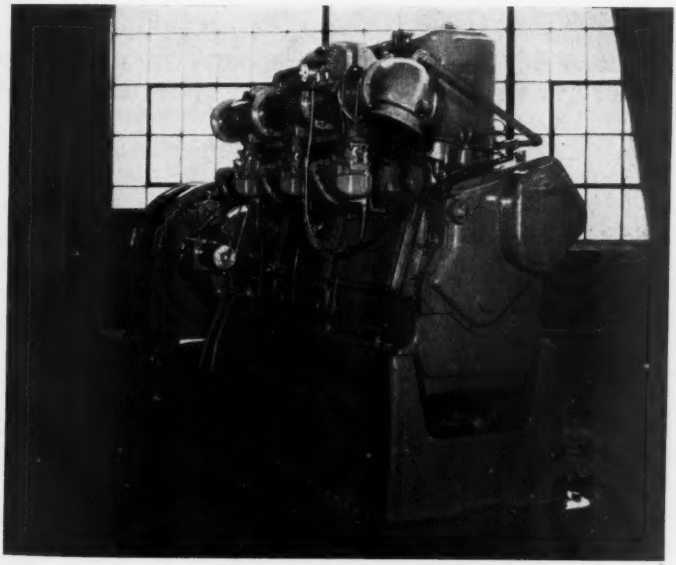

FIG. 9.—TYPICAL GASOLINE-ENGINE-DRIVEN GENERATOR.

Reinforcement in certain emergencies can be obtained by having a fire-department pumping-engine connect to one hydrant of a system and pump into another hydrant nearby with a valve closed in the main between the two hydrants. Operators who could use this service in an emergency should be familiar with locations in their system where the two hydrants with a valve between are available or can be installed.

Conclusion. In conclusion, I would sum up by making the generalizations that:

Large cities will usually find supplementary electric supply lines the best emergency supply. They should examine carefully what other customers are connected to the emergency line; get an exclusive line if possible; test the line frequently.

Small plants up to 25 or 50 hp. should look into the possibility of complete engine-driven, electric-generating units. With this type of emergency supply, trying to make the operation automatic should be avoided. The simpler it is, the more dependable.

The majority of plants falling between these two classes would do well to investigate direct-connected engine-driven pumps. With this type of supply, the accessories of the plant that may have to be operated in addition to the pump itself, should be carefully investigated; the fuel storage closely watched and the possibilities of refueling considered. If such a unit is provided, a trial should be made by operating with the normal supply absolutely cut off to see if any important element has been neglected.

The advantages of a Diesel-engine-driven unit should be investigated. The purchase of these units cannot be justified for emergency alone, but if there is a Diesel unit in operation, it should make the system, as a whole, unusually independent of outside conditions.

ACKNOWLEDGMENTS. The illustrations, except Figures 2 and 4, are taken from plants designed by Metcalf & Eddy. The pumping engine shown in Figure 2 was installed under the supervision of Richardson & Gay. The boiler plant of Haffenreffer & Co., illustrated in Figure 4 was designed and installed under the supervision of Cleverdon, Varney & Pike.

RESPONSIBILITY OF WATER PURVEYORS FOR THE QUALITY OF WATER DELIVERED

BY E. SHERMAN CHASE*

A recent decision of the Massachusetts Supreme Court and parallel decisions in England relating to the responsibility of water departments or companies for the quality of water received by their customers should be brought to the attention of the members of the New England Water Works Association.

Both the Massachusetts and English cases were brought as the result of lead poisoning due to the solution of lead in passing through lead service pipes before use for domestic purposes. The English decision was rendered by the Court of Appeal early in 1938 and the Massachusetts decision on Jan. 10, 1939.

In the English case a man and his wife claimed damages for personal injuries arising from the alleged breach of statutory duty by the Irwell Valley Water Board. The plaintiffs claimed that they had contracted lead poisoning from the water supplied by the Board. The Board's defense was that the water was pure to the stop cock and that there had been no evidence to show that the water was dangerous in itself at that point.

The Commissioner who heard the case in the lower court, found that the defendants had satisfied their statutory duty, but that this did not end matters. He found that the Water Board had a common duty above that imposed by the statute. The Board knew that the plaintiffs intended to use the water for domestic purposes and that there was a high degree of probability that the water would be conducted through lead or tin-lined pipes. Consequently the Water Board should have warned the customers to take precautions either by putting in a different kind of pipe or by drawing off a substantial amount of water before using. The evidence indicated that the plaintiffs had received no warning of any kind and the Commissioner held the opinion that the defendants were guilty of an act of negligence. Judgment was entered for the plaintiffs to the amount of about $4,000.

The Water Board appealed to the Court of Appeal, but the Court dismissed the appeal without calling on counsel for the plaintiffs. Lord Justice Greer giving the judgment stated that the Water Board had

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been warned over and over again that the water passing through lead pipes was liable to be contaminated before reaching the consumer, and that there was a duty on the part of the Board to supply water in such a condition that, when used, after going through lead pipes, it would be reasonably fit for domestic use.

Apparently this English case establishes precedent in England, because in the report of the decision it is stated that the Court had to consider, perhaps for the first time, whether there was more than a statutory duty incumbent upon the Board to exercise reasonable care that when the water reached the consumers it was reasonably fit to use. The Lord Justice said that there were means which might have been adopted to protect the water users,—one, to adopt measures to reduce the plumbo-solvency of the water, and the other, to circularize consumers, warning them to draw off water before using it for drinking purposes. The judgment read in part as follows:

> "The evidence is conclusive that if there was such a duty the board did not perform it. It delayed a very long time in installing apparatus which would render the water harmless. It did not adopt the simpler method of warning consumers, and it is no protection for the board to say that it was advised by the local authority that it might be dangerous to frighten people by sending out a warning notice.
>
> "From 1929 to 1935 a series of complaints had been made by water consumers that they were ill with lead poisoning. A long waiting period took place, in which no steps were taken to protect the unfortunate people who were drinking this lead contaminated water. I find it impossible to come to any other conclusion than that the board, through its agents, was negligent.
>
> "It would be lamentable if there were no remedy for the plaintiffs in these circumstances; the law of England would be very deficient in protecting the rights of water consumers."

The Massachusetts case relates to action brought by Earle R. Horton against the town of North Attleboro, tried in 1937, with a decision in favor of the defendant. On appeal, to the State Supreme Court, on exceptions to the trial judge's rulings, the exceptions were sustained.

The plaintiff, Horton, applied for a supply of water at his house in 1933. The plumber installed a ¾-in. lead service pipe from the property line to the meter, a distance of 145 ft. The town connected the service pipe to the street main by means of 27 ft. of lead pipe, making a lead pipe service connection of 172 ft. in length. The regulations of the Water Board provide that service pipes must be inspected by the Department and that the installation thereof must be made under the direction and with the approval of the Superintendent

of Water Works. The use of lead pipe has been almost universal in connection with the North Attleboro system.

Up to the time of the use by him of the water supplied through this lead service connection the plaintiff's health had been good, but thereafter it began to fail. In the following summer his trouble was diagnosed as "lead poisoning" and the evidence showed that it had been caused by the drinking water. Four parts of lead per million were found in samples of water which had stood in the pipe for 3 hours, compared with 1½ to 2¼ p.p.m in water that flowed freely through the pipes. As much as 8 p.p.m of lead were found in water that had stood in the pipe over night. Furthermore, the water contained 30 p.p.m of carbon dioxide.

Action was brought against the town in October, 1934, on two counts. The first count, claimed a warranty that the water would be fit for drinking after passing through the lead pipes, and the second count claimed negligence on the part of the town. The jury returned a verdict for the defendant on both counts. Exceptions were taken by the plaintiff to certain instructions and refusals to instruct on the part of the trial judge and on these exceptions the case was carried to the higher court.

The trial judge instructed the jury that the water was sold and delivered at the property line and that the defendant was not liable if the water was fit for human consumption at that point, even though it became unfit after passing that point, but if the water was unfit at the property line the defendant would be liable only for the injury caused to the plaintiff by the lead that was in the water at that point. This ruling was excepted to by the plaintiff, as was the judge's refusal to instruct the jury as follows: "1. The defendant in supplying water for domestic use impliedly warranted that it was fit therefor when consumed through pipes of a kind approved by the defendant's authorized representative. 2. When the defendant required that water which is sold for drinking purposes be conducted through pipe of iron, tin or lead, it expressed to the plaintiff its approval of lead pipe."

The trial judge ruled, without objection or exception from either party, that the town was bound by an implied warranty under the Massachusetts sales act. [Gen. Laws, Tercentenary Edit. Chap. 106, par. 17 (1).] The decision of the Supreme Court, prepared by Judge Lummus, however, stated,—"It could readily be found if not ruled on the undisputed facts, that the plaintiff made known to the defendant that the water was to be used for purposes which included

drinking, and that the plaintiff relied on the defendant's skill to furnish him pure water. But the weight of authority is to the effect that that provision of the sales act does not apply to the furnishing of a supply of water through pipes."

Judge Lummus stated, however, that this was not a question for them to decide in this case, because the basic ruling of the lower court judge, made without objection or exception, had become the law of the trial and that the exceptions to be considered were based upon the assumption that the basic ruling of the lower court was correct. The Supreme Court, after considering the purpose for which the water was furnished, ruled, "If there is a warranty under the circumstances of this case, as the trial judge ruled, it is a warranty that when water becomes the property of the plaintiff it will be reasonably fit to conduct through one hundred and forty-five feet of lead pipe into the house and then to be drunk." Consequently the court sustained the plaintiff's exceptions on the first count.

On the count for negligence the trial judge instructed the jury that the plaintiff must show the unfitness of the water for human consumption as delivered at the property line, and that this unfitness was due to negligence on the part of the town. The plaintiff excepted to the first part of this instruction and to the refusal of the judge to instruct the jury that "A town proferring to sell water for domestic consumption is under a duty to take such reasonable steps in the then state of common knowledge of those versed in the subject, as may be reasonably be expected to disclose whether the water is adapted for such use when transmitted through the kind of pipe which the town expects will be used."

Judge Lummus stated that, "the defendant owed the duty of furnishing at all times a supply of wholesome water so far as that could be done by the exercise of care, diligence and skill, which is ordinary and reasonable in view of the nature of the business." The court, therefore, found the trial judge in error in instructing the jury that the responsibility of the town stopped at the water gate and that the instruction requested by the plaintiff was correct in law and should have been given in effect. The court stated "The defendant was bound to take into consideration the fact that the water could not be drunk at the water gate, and to adapt its care to the fact that its water had to pass through a leaden service pipe in the house before it would be or could be used for drinking." In view of this finding the exceptions of the plaintiff on the second count were sustained.

The decisions in these two cases appear to possess possibilities of

far-reaching consequences to water works authorities. So far as the writer knows there has been no previous Supreme Court decision in Massachusetts which places the responsibility for the quality of a public water supply squarely upon the seller thereof. Damages for typhoid fever caused by impure supplies have been obtained in other states, but apparently no such cases have been brought in this state. Furthermore the ruling in the Horton *vs.* North Attleboro case establishes responsibility for quality of water on the seller thereof, even after the water has left its property.

The question also arises as to what the courts might rule in the case of qualities, which although not harmful to health might produce damage to equipment, such as hot water boilers or damage to material being processed, such as laundry work. Furthermore, there is the possibility of an industry, depending upon the satisfactory physical and chemical qualities of a public supply, being damaged as the result of changes in those qualities, such as an undue increase in iron content.

Obviously water departments and water companies are being held more and more accountable for the quality of the water they deliver for use and standards of quality are becoming more rigorous.

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SUMMARY OF CORROSION EXPERIMENTS

BY HARRY W. CLARK*

[*Read January 19, 1939*]

I am here today principally to give a short summary of certain corrosion work carried on by me or under my direction in the laboratories of the Massachusetts Department of Health during the thirty-seven years from 1896 to 1933.

It is, as you can see, largely old material but perhaps will serve as an opener to discussions of men who have done more recent work on this subject, men such as Speller, Pirnie, Robert Spurr Weston, Gilcreas, M. C. Whipple, Smith, Wiggin, Norcom, Moore and many others.

Papers and discussions by all of these men have appeared generally in the JOURNAL of this Association, but in some instances in other publications. Their work and their papers I am not intending to discuss at any length, as I hope that some of them are here today and will speak for themselves.

The part of corrosion that interests us most largely today, is the action of water, or bodies held by water, upon non-ferrous metals used for service pipes. This study was begun by me forty-two years ago on account of a considerable number of cases of lead poisoning in certain towns and cities in Massachusetts having lead service pipes, and as we went along we began to study the effect of corrosive waters upon other metallic or metal-lined service pipe including copper pipe.

My first paper on this subject of corrosion was published forty years ago in the Massachusetts State Board of Health Report of 1898, and the second paper by myself and Fred B. Forbes was published in the Annual Report of the State Board of Health for 1900. A large amount of practical and experimental work was carried on during those years, and the results were elaborated in those two papers. This work cannot be fully summarized in this short paper, but amongst other things it was clearly shown and stated in the first paper that the clear and practically colorless water supplies that most actively attack lead were those containing the most carbonic acid. All of the towns and cities where cases of lead poisoning had occurred up to

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that time, with one exception, have or had ground water supplies. These municipalities were few in number, however.

In my second paper, I stated again that the results of the investigations seemed to show that the cause of corrosion was the presence of a considerable volume of free carbonic acid in certain ground waters, and I also stated that while many laboratory experiments made by us had shown that while pure soft water, especially when containing dissolved oxygen, was under certain conditions corrosive, and that other bodies in water had a solvent action, yet taking into consideration our entire investigation we found that in actual practice, with the conditions prevailing in the service pipes of a distribution system, potable water in Massachusetts to have any corrosive action must be soft and contain considerable carbonic acid. I still believe that the statement is almost invariably true when dealing with lead, brass or copper service pipes in this state. I am on record, however, in papers and discussions of this subject that certain other constituents in water have an effect upon accelerating or preventing corrosion.

Statements have been made that free oxygen is always the principal factor in this action, but we all know that the surface waters of Massachusetts are almost invariably practically saturated with dissolved oxygen, yet these waters have generally very little corrosive action on non-ferrous service pipes. At the same time, these waters are low in carbonic acid. Many samples of water collected by us from towns having lead service pipes and supplied with surface waters softer than the average ground waters of the state did not show significant corrosion of lead by these waters. You can place pieces of any kind of metal pipe in jars, or bottles of water from almost any municipality and generally get solvent action, but the conditions in these bottles are very different from those prevailing in the service pipes of a water system. Moreover you cannot, generally speaking, obtain consistent and reasonable results in this way. Gilcreas gives results of studies of two Long Island water supplies and states "that in view of the accepted theories regarding the influence of dissolved oxygen on the corrosive action of water, the results were rather anomalous particularly as they are concerned with ferrous metals" and he also states "further study of these and similar conditions seems essential to our knowledge of the corrosive action of water toward metals and especially of the influence of dissolved oxygen in accelerating such action."

We all know that dissolved oxygen in iron pipes, steam boilers, etc. is generally a very active factor in corrosion of iron but I do not believe, as I have just stated, that it is the active agent in this respect in non-ferrous pipes.

Only a few experiments were made in those early days in regard to the corrosive action of water upon copper, but such as were made indicated that the ground waters and surface waters of the state took only a minute amount of copper into solution compared to the amounts of lead taken up by some of these waters from lead pipes.

In 1910, the author and his then principal assistant at the Lawrence Experiment Station, Mr. Gage, published a paper in the report of the State Board of Health for that year in regard to the relative corrosion of metal pipes by waters before and after purification, with a rather lengthy review of the literature up to that time in regard to corrosion, and I believe that in this paper the fact that oxygen was the potent factor in corrosion of iron pipes, hot water systems, steam boilers, etc. was clearly brought out.

In 1927, I read a paper before this Association upon the corrosion of non-ferrous pipes and in this paper gave tables dividing corrosive and non-corrosive ground waters into two classes as distinguished by the amount of carbonic acid present, and I again called attention to the fact that surface waters practically saturated with dissolved oxygen were not, when carried in non-ferrous service pipes of a water supply system, corrosive except in rare cases. Moreover, the less corrosive of the ground waters contained not only less carbonic acid than the more corrosive but a greater volume of free oxygen than present in the corrosive ground waters. In this paper some special work was described that we had carried on with twenty-three ground water supplies of the state, largely because of troubles experienced in some cities and towns supplied with these waters, by the corrosion of certain amounts of iron, copper and brass pipe and their fittings. As a result of these investigations, it was found again that little trouble was experienced by corrosion of these pipes by waters having 17 p.p.m., or less, or carbonic acid; but in waters having a greater amount than this, corrosion did occur. Much work was done also to show the action of surface water supplies upon unused copper and brass pipes, and the results of these experiments showed that while these surface water supplies, when passing slowly through new uncorroded and uncoated lead pipes, took anywhere from 4 to 40 p.p.m. of lead into solution, yet under the same conditions the amount of cop-

per taken into solution from new pipes was in one case only one-twenty-fifth as much as lead, in a second case one-hundredth as much, in a third case, one-tenth as much, in a fourth case one-seventieth as much and in a fifth case one-thirty-fifth as much. That is to say the amounts of copper were exceedingly minute, or as an average one-fiftieth as much copper as lead was taken into solution by these waters.

Other work, from time to time showed similar results to those I have quoted here. In addition to the work already quoted as carried on during those years between 1920 and 1930, we studied the action of various waters on new brass and copper pipes, 25 ft. in length, installed for this purpose in the cities of Newton, Lowell, Lawrence and Boston.

The Newton and Lowell supplies are ground water; Lawrence a filtered surface water, into which some ground water enters; and, of course, Boston has the Metropolitan supply. While the copper taken from these new uncorroded pipes was, generally speaking, greater in amount than from service pipes in use, yet the amount so taken was exceedingly small compared to the amount of lead that we had found taken from new, lead service pipes. In fact, about all of our analyses showed copper to be present in amounts less than 1 p.p.m., but occasionally larger amounts were found with those new uncorroded pipes.

With the experimental copper tubing 200 ft. long installed by Mr. Finneran of the Boston Water Department at this time, the average amount of copper in samples of water that had stood from 24 hours to seven days in the pipes was less than 0.5 p.p.m. and in the running samples practically 0.1 p.p.m. Experiments with brass pipes showed that they yielded much zinc when used in connection with ground waters but generally only minute amounts of copper. Let me state here also that in other work we found minute amounts of copper in ground and surface waters that had not passed through copper pipes.

In fact, all this work that I have briefly summarized, and other studies and observations made from time to time, have seemed to prove that while the amount of copper taken into solution from copper service pipes even by corrosive ground waters is very minute, yet the use of such pipes with some water supplies causes at times objectionable conditions because of the staining of bathroom fixtures, kitchen utensils, etc. Nobody cares to see these blue, or yellow-green, stains.

I have just read a statement, however, in the JOURNAL of the Maine Water Works Utilities Association that these stains can be removed by Carbona, i.e., carbon tetrachloride, and, of course, other solvents will effect this result.

In regard to the toxicity of copper I can, of course, say little except that I personally have heard of but one case of copper poisoning that was ascribed to drinking water that had passed through copper pipes and been stored in copper tanks, and I can quote again from one of my papers summarizing the results of studies in England on this subject. They seem to be sure on that side of the water that the amount of copper taken from copper service pipes in water supply systems is not toxic. In fact, quotations from the English Manual of Pharmacology, from Dr. Dixon and an article in Forensic Medicine and Toxicology and Dr. Thresh seem to prove, according to them, that there is no evidence that man is ever affected with copper poisoning from the use of copper service pipes and that the existence of such poisoning is unknown. These Englishmen state that each person takes into his body daily 20 milligrams of copper and that so long as the total amount of copper taken into the body does not exceed 100 milligrams daily there can be no question of injury to health. One hundred milligrams is about the amount we should find in 54 gallons of water when there happens to be 0.5 p.p.m. of copper in the water.

These are English opinions and you can believe them or not, but personally I think there is much truth in them, and later English and American studies confirm these conclusions.

Quoting again from the Maine Water Utilities Association Journal I find that Mr. R. S. Baker, Service Engineer of the American Brass Company states as follows: "As far as we have been able to find out from discussions of medical men and through the study of medical literature by a competent authority, the amount of copper which may be dissolved under ordinary conditions in a domestic water system is not in any way injurious to the health of the users of the water". Of course, this statement is from a man whose firm has brass pipe to sell but I think you can believe it.

In some of the State Board of Health work as I have stated, minute amounts of copper were found in ground and surface waters that had not passed through copper pipes. In fact, the human system always contains copper taken in with shell-fish, especially oysters, and such grains as wheat, barley, etc., and many other foods also contain copper.

Remember, however, that this paper is not written to boom either brass or copper pipes but to give a fair picture of what may be expected when they are used, and personally, I believe they can be used, if one wishes to, with many water supplies but should not be used with corrosive waters even though the stains on bathroom fixtures, kitchen utensils, etc. can be removed by Carbona or by other means, or the water rendered non-corrosive by the use of lime or soda ash. Gilcreas, in a study of Newton water, states that soda ash treatment at Newton costs about $5 per million gallons or $10,000 per year. I might add also that conflicting results obtained by various workers in regard to the corrosion of non-ferrous pipes are probably due to certain differences in the water in different parts of the country that have not always been sufficiently recognized.

For example, Smith of the American Brass Company states that where certain types of water are treated with lime to reduce corrosiveness and the pH is held at about 8, the treated waters are not corrosive to 60-40 brass, but that the same treatment with other waters will not reduce their corrosiveness and that the mineral constituents of the water have as much bearing on corrosion as the pH value. Smith states also that 60-40 and 85-15 brass pipes are not now generally used as service pipes and recommends copper pipes.

Moore and Bean and others make even more positive statements in regard to the little value, in some instances, of pH and carbonic acid determinations in deciding the corrosive action of the water. I imagine that with some waters this statement may be correct, especially water with much mineral matter in solution, but my experience has been largely with Massachusetts waters, and I am wondering if the results of all these men are from service pipes actually in use in a water system or are from experiments with pieces of pipe in water.

I read an article within recent months by Buswell entitled "Water Isn't H_2O". Sometimes it does act as if it were not, owing to its varying character in different parts of the country and the amount or kind of matter in solution in it.

Finally always try to determine what kind of a water you are dealing with before deciding what service pipe to use, and in this respect the chemist is sometimes a handy man to have around. There is undoubtedly still a lot to learn about corrosion by water in different parts of the country.

Discussion

Arthur R. G. Booth.* After what Mr. Clark has said, there is not much that I can say. I had the honor of serving under Mr. Clark for some 31 or 32 years, and about all I know about water I have learned through him.

Regarding the question of the toxicity of copper, I looked up a few references recently, one of which was in the Journal of this Association (March, 1927) by Dr. F. B. Mallory, with which you are probably all familiar. Dr. Mallory said there:

"It is my function at this meeting to call your attention to the dangerous effects of small quantities of copper taken into the body over a long period of time. . . . Chemical examination of the liver and other organs from patients dying of various diseases shows that copper is often present in small amounts. This indicates two things, first that we are constantly exposed to copper, and second that we can handle a certain amount of it without danger. How much, it is difficult to say,—5 to 10 mg. a day; it may be less or more. . . . Some people may be injured by very small amounts of copper which would not affect other people in the slightest. On this account, exposure to copper in any way should be reduced to the minimum."

In connection with Dr. Mallory's statement it may be interesting to note that Drs. Flinn and von Glahn, in the Journal of Experimental Medicine, published by the Rockefeller Institute, (January 1, 1929), state:

"The theory of Dr. Mallory that copper is the etiological agent of the human disease 'hemochromatosis' is shown to be founded on a wrong hypothesis for he bases his theory on observation of pigmentation in the livers of animals. This pigment has now been shown to be due to exogenous origin. As the evidence exists the quantities of copper that are found in our food and drinking water will not injure any human organ. In fact, evidence is accumulating showing that small amounts have a beneficial effect on the blood in cases of anemia."

I remember the investigation that Mr. Clark described, of the action of copper on water, or water on copper, in which over the state we found that in those municipalities which had no trouble with corrosion the carbonic acid content was under 17 p.p.m. while in those having trouble it was over 17 p.p.m. That was very interesting, and it goes to show that the carbonic acid content of the water definitely does affect the corrosive action of the water on the pipe. The amount that will be eaten off the pipe of course is problematical.

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We made an experiment recently at the laboratory at the State House on galvanic action. When two 4-in. sections of dissimilar pipes, copper being one of them, were placed in one-quart jars of water which had or had not been treated with soda ash, the amounts of copper dissolved were remarkably small, being not more than 0.2 p.p.m. after having stood in contact with the water for several months. Therefore, it leads one to believe that the amount of copper in water that can be dissolved is very small.

According to the latest book by A. Wynter Blyth on "Poisons, Their Effects and Detection," 1920, Fifth Edition, Blyth says:

"It has been calculated that the ordinary daily food of an average man contains 0.95 milligrams of copper. That is to say, that, neglecting altogether foods artificially contaminated with copper, each of us eats daily about 1 milligram of copper." (0.015 grains).

It seems to me that water drawn through copper pipes at the present time, if it has not over 0.2 p.p.m. of copper which is the standard set, I believe, by the United States Treasury Department—will not be harmful for us to drink.

Francis H. Kingsbury.[b] It does not seem to us in the State Department of Public Health that there is any real danger to health from drinking water that has passed through copper pipes under conditions of ordinary experience. However, we do receive some complaints about green stains on fixtures and laundry. These green stains are bound to occur with some waters in the use of copper pipe. One gets brown stains with some waters in the use of iron pipe but people are more used to this.

Copper pipe and copper tubing, as any mechanic knows, are very easy materials to work. It seems that our chemists must condition the water so that it will give us a minimum of corrosion. If we are unfortunate enough to have a water that will seriously corrode, I personally believe that it is time to look about and correct the situation by some appropriate treatment of the water or rearrangement of the house piping to avoid the use of dissimilar metals.

F. G. Smith.[c] I was quoted in Mr. Clark's paper as stating that 60-40 brass pipe and red brass pipe were not used for services so much as formerly and that they were being replaced by copper tubing. That statement is no longer fully correct. Red brass pipes are still used for services. Muntz metal pipes are sometimes used for services, but, if they are, it means trouble because 60-40 brass

[b]Massachusetts Department of Public Health, Boston, Mass.
[c]American Brass Company, Waterbury, Conn.

is not a suitable structural material to bury in the ground and to withstand corrosion and the stresses due to settling of the ground.

Mr. Clark also quoted me as saying that the mineral content of the water had some bearing upon its corrosiveness, as well as the pH value. That statement was based on practical experience. In 1921 or 1922 the American Brass Company began to promote the sale of brass pipe. We started in with the knowledge available about brass pipes then in use. They lasted a long time in many places. After a few years, we found that some brass pipes did not last so long in some places. Those brass pipes were Muntz metal. One of the places where they did not last long was Newton, Mass. We conducted an investigation to find out why the pipes failed in some places and did not fail in others, and the practical results we found checked those given by Mr. Clark in his original paper on the investigation of waters in Massachusetts. In other words, soft ground waters with high carbon dioxide were corrosive while surface waters, which might be soft too but which had very little carbon dioxide, were not so corrosive. But we found, after having a great many analyses made, trying to balance some analytical results against the actual effects on pipes, that the pH value, which is commonly thought of as the measure of acidity or alkalinity of the water, did not always agree with the facts found, that water high in mineral content, high in hardness, might have high carbon dioxide and still not be very corrosive, although the pH value would be in the neighborhood of 7 or a little less. A paper published in the Journal of the American Water Works Association in June 1936, by Professor Langelier of the University of California, shows why the mineral matters, especially the calcium and the total solids in the water, have a bearing upon corrosiveness as well as the pH value. In our laboratory we make analyses of water from all over the country and can correlate the effects with the analyses. We find, if we use Langelier's formula, lately published in monographic form, that the relative corrosiveness is indicated by his formula.

The question may be asked, "Has anyone had any experience with tinning of copper tubing to prevent green stains?" We furnish tinned copper tubing for that purpose, and we are carrying on experiments all the time. In one practical experiment, a long line of copper tube, untinned, was run from a spring where the water was very soft and high in carbon dioxide. When the water was drawn after standing for 24 hours it had 12 p.p.m. of copper in it which I think is more

than anybody in the room will agree should be in drinking water. We replaced that copper tube with one that was tinned, and it has been in service now for a couple of years. The maximum amount of copper that we now find is about a half a part per million. This is about as little as we can determine with certainty. In other words, the water now coming through the tube is practically free from copper.

President Sampson. Can you give us some idea as to the cost of tinned copper tubing?

Mr. Smith. The ¾-in. Type K copper tubing, the most common size used, tinned inside and outside costs per foot about 25% less than untinned brass pipe of the same nominal size.

Carter S. Cole.[d] I came to listen more than to talk, but there are some points that have been raised here on which I think I can give you some additional information. One is as to the amount of copper that we get in our daily food. I have a table[1] that gives the amount of copper in serving portions of various foods, and each and every one of us in this room at our lunch today ate 1.10 mg. of copper. That certainly is of the order of the amount of copper that we get with the most corrosive waters when we use untinned copper tubing. The foods we had today are really very low in copper content. Many other foods are much higher. At the University of Wisconsin[1] they have calculated that an active working man can regularly in his diet eat 4.81 mg. of copper per day. Living in this part of the country, a good many of us eat oysters, and that is one food that has considerable copper in it. A serving portion of oysters would have been 3.38 mg. of copper.

The U. S. Public Health Service[2] limit of 0.2 p.p.m. of copper is quite generally recognized today as being extremely conservative. Dr. Sidney S. Negus[3] in a paper published in the Journal of the American Water Works Association points out that "a person drinking two quarts of water a day (the average intake) with this much copper in it would be getting approximately 0.4 mg. of the substance. The body requires at least 2 mgs. a day, so 0.2 p.p.m. of copper is probably helpful, certainly not harmful." The Water Works Commission in The Netherlands,[4] after a careful review of all the work on the subject, came to the conclusion that 3 mg. per l., that is, 3 p.p.m., would be permitted in water that had stood for 16 hours, and 2 p.p.m. in water that was running. The whole point is that you will get a disagreeable stain from the copper pick-up long before the

[d]Copper & Brass Research Association, New York, N. Y.

amount of copper can in any way be injurious to health. Small amounts of copper are beneficial to health and are used in medicine today, particularly in the treatment of anemia.

The waters that will pick up small amounts of copper are few and far between. They are mostly on private supplies. Very few public supplies today are so corrosive as to do that. A few waters in New England are soft and high in CO_2, but they can be handled, with our present knowledge, by two methods. One is by treating the water so as to tie up the CO_2 as bicarbonate, so removing its aggressive character, and the other is by using tinned copper tubing. When water is treated by a water company, lime is probably the most economical way to handle it, but for private supplies marble or limestone chips are much better and quite effective.

I have had personal experience with a water with a pH of 4.7, a hardness of about 16 p.p.m., and a free CO_2 of 27 p.p.m., a rather aggressive water. It was picking up 5 p.p.m. of copper from untinned copper tubing. A small marble chip installation along the lines of that used near Harrisburg by Glace[5] and also reported by Cox[6] in the American Water Works Journal, completely cured that trouble and eliminated all copper pick-up. That was four years ago, and it is still going strong. I had occasion just last Saturday to talk to a friend of mine who goes to that place regularly, and he told me that the water was excellent.

Donald G. Calderwood.* The consensus of opinion seems to be to the effect that in many installations copper is satisfactory. But the New Hampshire State Board of Health has taken a rather opposite stand, and I want to read a sentence taken from the December issue of the New Hampshire Health News: "While nothing contained in the regulations specifically places any restriction upon the use of untinned copper tubing, it seems safe, on the basis of our observation, to advise of its unfitness in substantial lengths for a majority of our waters."

That definitely, to my mind, states that the Board is against untinned copper tubing in conjunction with most of the waters, and I believe that the waters of New Hampshire are very similar to the waters encountered in other parts of New England.

Mr. Cole. The waters in New Hampshire, particularly in private supplies, are quite low in hardness, high in CO_2 and low in pH, and are of the type that might pick up small amounts of copper, so as to

*Pennichuck Water Works, Nashua, N. H.

give stains. As such they should be handled either in tinned copper tubing or by treating the water to remove its excessive corrosiveness.

The apparent effect of small amounts of copper can be multiplied in two ways, that is, as far as showing it is concerned. One is by the slow drip of a faucet, where evaporation concentrates the metallic content of the water so that the stain shows up even for very small quantities; the other is when the fatty acid radicle in soap forms, with copper, a molecule of large size, so that the color is again made more prominent. But it does not necessarily mean that an excessive amount of copper is present if these effects are observed.

Percy R. Sanders.[f] I think the article in the bulletin of the New Hampshire State Board of Health which Mr. Calderwood spoke about referred to ground water supplies and springs for farms and country estates.

For these, the Board advises against the use of copper tubing on supplies that are high in CO_2; or otherwise suggests the use of lime treatment. In the Concord supply we have about 600 ft. of 1½-in. copper tubing serving one house. Analysis of the water from this house revealed no trace of copper whatsoever. The State Board, as I understand it, does not want people to use copper tubing on supplies unless this use is approved.

Edward W. Moore.[g] The discussion of New Hampshire waters calls to mind the case of a private water supply located in the central part of the state. This supply was investigated in 1929, under the direction of Professor Fair. The water was derived from a spring surrounded by pine woods, and had the following characteristics:

Carbon dioxide	15.5 p.p.m
Alkalinity	27.5 p.p.m
Hardness	28.5 p.p.m
Dissolved oxygen	4.6 p.p.m
pH	6.6

In passing through 2000 ft. of 2-in. copper tubing, the water picked up an average of 6 p.p.m. of copper.

Samples of the raw water were subjected to the following treatments:

1. Aeration, secured by allowing drops of water to fall through a height of 4 ft.
2. Treatment with sufficient lime to neutralize all the CO_2.

[f]Superintendent, Concord, N. H.
[g]Harvard Graduate School of Engineering, Cambridge, Mass.

3. Filtration through a 4-ft. bed of marble chips, 3 to 8 mm. in diameter, at the following rates:

a. 0.25 g.p.m. per sq. ft.
b. 1.14 g.p.m. per sq. ft.

These samples were sealed in lengths of the same copper pipe as that used in the installation, and allowed to stand for 48 hours. The samples were then analyzed for copper, and showed the following results:

Sample	p.p.m. Copper
1	0.5
2.	0.06
3a	0.3
3b	1.4

Although the lime treatment, and the filtration through marble showed some promise, both were discarded on practical grounds, the lime treatment because of the equipment and attention required, and the marble filter because of lack of available head and the difficulty of protecting the filter against freezing.

The final solution of the problem was the replacement of the copper pipe with cement-lined iron pipe. This cement-lined pipe increased the hardness and alkalinity of the water to some extent, but this effect was regarded by those using the water as less objectionable than the presence of large amounts of copper. The amount of material leached from the pipe decreased in course of time, as the following table shows:

	Water Delivered (p.p.m. $CaCO_3$)		
Time After Installation of Cement-Lined Pipe	Hardness	Phenolphthalein Alkalinity	Total Alkalinity
5 days	60	35	42
2 months	35	13	34
4 months	33	7	33

Mr. Smith. A certain supply carried about a half a part per million of copper, and when at a certain house clothes were washed, such things as Turkish towels that are fuzzy and pick up anything in the water, green stains would be left on them. I found that in other houses in the same town, where there was as much copper in the water, did not have any green left on the linen when it was washed. I found that the maid in the house in question had been in the habit of washing clothes with only half as much soap as should have been used in the machine, so that before the washing was

completed the soapsuds had all disappeared and there was nothing left but a pale gray colored water. Then, of course, without enough soap or alkaline material to counteract what acidity there was, the copper united with the soap and formed copper oleate, which impregnated the cloth. The simple remedy was to use a teaspoonful of sal soda or Oakite in the washing machine, and enough soap to keep a lather while it was working, also to put a teaspoonful of sal soda in the rinsing water. The clothes then came out just as clean and white as in any other home. The green in that case was due more to the way the clothes were washed than to the very small amount of copper in the water.

PRESIDENT SAMPSON. Mr. Clark spoke of 17 p.p.m. of CO_2 as a critical value. I would like to ask what proportion of New England waters have that amount?

MR. CLARK. Speaking about ground waters entirely, I can say that a large proportion of the ground waters in use in Massachusetts today have less than that amount.

I think perhaps you all noticed, or, at least, some of you noticed that I did not mention my opinion of pH in this subject. I did not get into that at all and I did not intend to. I am on record in various places, however, as saying that mineral matter in a water does have an effect upon the corrosiveness of the water, and some influence, of course, on the pH value.

My whole paper was simply to show how small an amount of copper is really taken into solution by even the most corrosive waters, and that if we go by the medical authorities hardly any of the public water supplies that pass through copper service pipes take enough copper from these pipes to cause injury to health. But certainly some of the ground waters are corrosive enough to cause copper pipes to be a nuisance in a house, and it has always seemed to me that one can get away from this trouble by not using copper pipe. There are other pipes that one can use for service pipes besides copper. It is more or less costly to treat a water with soda ash, and it is more or less of a nuisance to keep cleaning off stains.

In regard to what Mr. Smith said concering that long service pipe and water containing 13 p.p.m. of copper, I stated that I knew of only one case of copper poisoning, or one reported case, from water. This was caused by a long copper service pipe, with the water stored in either copper or copper-lined tanks. I might say right here that this case was reported to me quite a few years ago by the partner of our president. What I quoted from the English authorities shows

that they have much more copper in some of their drinking water than I believe any of the men who have spoken here would say should be allowed. Certainly we do not get much copper from service pipes of the average length.

MR. SMITH. Perhaps the subject of corrosion of copper pipes which has come up today is a part of the natural development, we will say, of the sale or use of brass and copper pipe. The American Brass Company, and I am certain all the other brass companies, offer services where we send out to anyone interested a carton containing bottles for water samples. We analyze the water and report whether it is more or less corrosive, whether it will pick up copper, and whether tubes or pipe should be plain or tinned. If there is anyone here who has any doubt about what he should or should not use, he should ask his supplier for that sort of information. It is very seldom that we get a request for a water analysis from a location where it is not required. Most of the analyses we make show that the waters are corrosive and we recommend tinned tubes. That is the invariable recommendation because those who do not have the trouble do not ask the questions. Every other brass and copper company—the Copper and Brass Research Association for the companies—does that sort of work and gives that sort of advice.

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SAFEGUARDING RHODE ISLAND WATER SUPPLIES AGAINST FUTURE DISASTERS

BY JAMES J. DILLON*

[*Read November 17, 1938.*]

Before offering any suggestions or formulating any plans for safeguarding the public water supplies of Rhode Island against future disasters, it will be well to outline briefly the damage caused by the recent hurricane, flood, and tidal wave. All 41 public water supplies in operation in Rhode Island on September 21 were confronted with some sort of problem that had to be solved in order to maintain their service. Those problems may be grouped into seven classifications:

1. *Power Failure.* All of the water plants were confronted with the disruption of outside electric power service.

2. *Leaks on Distribution Systems.* Hydrants and mains were broken by fallen trees and being hit by falling buildings, etc. The East Greenwich and Pawtuxet Valley supplies had such bad leaks that they were unable to supply consumers in the high-pressure areas and were pumping almost twice the normal amount of water. At Newport, two 8-in. mains were broken and running all night following the storm. However, it was possible to maintain the pressure in this instance. The Bristol County supply, the hardest hit in Rhode Island, had so many leaks, coupled with the fact that no water was being pumped, that the standpipe had to be shut off in order to hold some ¾ m.g. of water for emergency.

3. *Destruction of Reservoirs.* At Newport, South Easton's Pond, the larger of two raw-water reservoirs, was completely destroyed. The dam was washed out in several places and the pond entirely drained. However, it was possible to shift the draft over to North Easton's Pond, which was only slightly damaged, and to continue in operation.

4. *Flooding of Reservoirs*—particularly by salt water. This happened in the case of the Bristol County Water Co. whose main impounding reservoir and treatment works are located on the mouth of the Kickemuit River in Warren, where the river empties into the salt water. The exceptionally high tide flooded over the dam, leaving the reservoir with about 25% of sea water in it. This rendered the

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water not only unpalatable, but also made it impossible to put the steam plant in operation.

5. *Flooding of Purification Plants.* At Jamestown, the sedimentation basins and clear well were flooded with contaminated water which was pumped into the mains, thus contaminating them. Sterilization of the mains required almost a week.

6. *Decreased Filter Runs.* Due to the churning of the water in the reservoirs and settling basins by the high winds, the load on filters was tremendously increased, and the filter runs in some cases were reduced to 1½ hours.

7. *Increased Chlorine Demand.* As a result of the conditions described, brought about by the high winds, the chlorine demand of the water was greatly increased. It was also deemed advisable to maintain higher than normal residuals as an added safety measure.

So much for the damage done. What did we learn from this experience? Where did we fail to do something we should have done? How will we handle the next disaster?

Since the problems presented by the storm of September 21 cover almost every possible type of disaster that can affect a public water supply, a study of these problems, and how best to solve them before they appear again should be sufficient safeguard against any future disaster.

Let us consider the same seven points as covered in the outline of the damage suffered by the water supplies and discuss the needs for overcoming or forestalling them in future emergencies.

1. *Power Failure.* To cope with this situation, some sort of auxiliary power equipment should be part of every plant and should be of sufficient size to maintain at least normal operation.

As to the type of auxiliary power, the superiority of the hydroelectric plant was demonstrated in the case of the Providence and the East Providence supplies. Both these plants are equipped with generators capable of supplying their power needs and both suffered no interruption in operation.

Gasoline and Diesel installation proved their worth in maintaining the smaller plants in operation. Regarding the use of steam as an auxiliary source of power, there are several drawbacks. One of these was forcibly demonstrated in the case of the Bristol County Water Co. Here was a perfectly good steam plant ready to go, but no fresh water to feed the boilers. Thus if steam is to be considered for auxiliary power purposes, other factors should also be taken into account. Unless a supply of fresh water, suitable for the boilers is

absolutely assured, a steam plant should not be considered.

2. *Leaks on the Distribution System.* There are three factors that enter into the program for eliminating difficulties from this cause.

a. The advantage of hydrants that do not leak when broken are obvious.

b. Adequate storage of treated water under pressure. If several days supply of water is in reserve, it will allow time to shift over onto the auxiliary source of power and will also assure uninterrupted service while the broken mains are being repaired.

c. Shut-off valves, adequate both as to number and as to location, in order to facilitate the repairing of leaks. It would be well to mention at this point, also, that plans of the distribution system should be readily available to facilitate the location of the mains and valves.

3. *Destruction and Flooding of Reservoirs.* Apparently, there is no way of determining how high or how strong a dam or dike, constructed near the ocean, should be in order to be impregnable against the forces of Nature. The only other course, therefore, is to plan on having such reservoirs destroyed and lay out a course of action in accordance with that plan. This had been done at Newport. Here there are four intake lines to the pumping station, making it possible to operate on water from any one of four scattered sources. This arrangement proved to be the salvation of the Newport system during the recent period of stress, whereas the lack of intake lines from at least one inland reservoir to the Bristol County supply meant that it had to close down for 48 hours.

4. *Flooding of Purification Plants.* There is but one solution to this problem: to locate the plant on as high ground as possible, beyond the reach of floods and tidal waves.

5. *Decreased Filter Runs.* Covered sedimentation basins would minimize this difficulty when caused by high winds; however, the action of high winds on the water in reservoirs also contributed its share. Adequate filter area should therefore be provided at each plant.

6. *Increased Chlorine Demand.* Duplicate chlorinating apparatus has been advocated as good waterworks practice for some time. We have no such installation in Rhode Island. As a result, when in the case of Bristol it became necessary to sterilize the distribution system, we had to accept the kind offer of Wallace and Tiernan of an emergency machine. Had there been duplicate equipment at that plant, the huge doses of chlorine necessary could have been added as

soon as the pumps resumed operation. Other minor floods in various parts of Rhode Island have also shown the desirability of duplicate chlorinators.

Whether hurricanes are going to strike Rhode Island oftener than every 123 years or not is problematical. But I do feel that, by preparing for a repetition of the September 21 disaster, we shall be able to cope with any freak situation that Mother Nature may thrust upon us.

Before closing I would like to mention the truly amazing spirit of coöperation shown by the superintendents and operators of the public water supplies of Rhode Island on the one hand and the public on the other. Every suggestion and recommendation of the State Department of Public Health was carried out to the letter and with an enthusiasm that was almost unbelievable.

PROTECTION OF PUBLIC WATER SUPPLIES IN MASSACHUSETTS DURING THE FLOODS AND HURRICANE OF 1938

BY JOSEPH C. KNOX*

[*Read November 17, 1938.*]

During the week of September 18, 1938, Massachusetts was called upon to cope with a major disaster in the form of severe floods and a hurricane. The effects of the floods were in a large measure similar to those encountered during the floods of March 1936, but the hurricane and its disastrous effects were a new experience at least in the annals of this generation. Moreover, the hurricane caused a tidal wave that devastated certain coastal sections of the state in which major catastrophies had been virtually unknown.

The flood conditions presented a grave menace to public health and seriously threatened the purity of some of our public water supplies. The hurricane paralyzed communication and transportation facilities and handicapped the work of flood-relief organizations and the rehabilitation of affected water supplies. The damage to water works and the disruptions to water service, occasioned by the flood, consisted of inundated sources of supply, flooded pumping stations, power failures and damage to distribution systems by the washing out of mains. The hurricane caused many power failures at pumping plants and treatment works and, in a few cases, damage to standpipes and some minor damage to distribution systems. From preliminary estimates available to the Department of Public Health, the damage to water works systems in Massachusetts was about $549,000.

Cause and Magnitude of Floods. The severe floods resulted from heavy rainfall that began on September 17 and continued through September 21. The average rainfall in Massachusetts for the month of September, amounted to 8.99 in. as compared with the normal rainfall of 3.66 in. This rainfall was particularly intense in the Connecticut River Valley, especially on the drainage area of the Chicopee River where the records of 19 stations showed a precipitation for the month of September of 15.71 in. of which 12.49 in., or 80%, fell during the 5-day period of September 17 to 21 inclusive. The rainfall gage at Barre showed a record rainfall of 19.59 in. during the month, of

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which 17.03 in. fell during the 5-day storm, while the gage at Hubbardston recorded 18.28 in. for the month, of which 15.60 in. fell during the 5-day period in question.

Such unprecedented rainfalls resulted in extreme flood conditions in certain of the river valleys, particularly those of the Ware, Quaboag, Chicopee, Swift, Hoosic, Housatonic, Millers, Deerfield and Westfield rivers. An illustration of the effects of rainfall of this magnitude is the flow of the Ware River at Coldbrook which reached 14,000 c.f.s. as compared with a flow of 6,000 c.f.s. recorded during the 1936 flood.

The flood stages on the larger rivers, the Connecticut and Merrimack, were less than during the floods of 1936 but greater than in the flood of 1927. However, the Connecticut River at Holyoke reached an elevation only 1.9 ft. less than that of the 1936 flood, while the peak of the Merrimack River at Lowell at the Pawtucket Dam was 7.4 ft. less than in the 1936 flood. In the case of the Charles River, the flood stage at Dedham Meadows was 3.1 ft. less than in 1936 and 3.9 ft. less than the maximum peak reached during the flood on this river in July, 1938.

It will be recalled that the 1936 flood occurred during the early spring, and while there was an abnormally heavy rainfall, the melting snows on the watershed greatly contributed to the amount of runoff. The flood in September, 1938, was the result of unprecedented heavy rains during a period when the flow in our streams is normally low; likewise, the flood that occurred on the Charles River in July of this year was caused by localized heavy rainfall during a season when extreme runoff conditions are wholly unexpected.

Prior to the flood of 1936, with the exception of the flood in the western part of the state in 1927, Massachusetts had not been affected by serious flood conditions for many years, and it was the prediction of authorities on the theory of probability that such conditions were to be expected but once in a long span of years. The floods of 1936 and 1938, occurring within a period of slightly more than two years would seem to indicate that the occurrence of such conditions cannot be prophesied. The flood on the Charles River in July of this year, which exceeded both the March 1936 and September 1938 floods, demonstrates the possibility of localized floods on the smaller rivers even during a season when flood conditions are least to be expected.

The Hurricane. The hurricane that visited Massachusetts with such devastating force on September 21 was probably the severest storm of this nature and the most destructive one of which we have

record. The normal path of such cyclonic disturbances, which appear in the vicinity of the West Indies, is westerly and northerly to the vicinity of Cape Hatteras and thence northeasterly to disappear over the Atlantic Ocean. The meteorological conditions during the early part of the week of September 18 showed a high-pressure area over the ocean eastward of Cape Hatteras, which diverted the storm from its normal path and caused it to follow a low-pressure trough generally along the Connecticut River Valley.

Historical records inform us that hurricanes and other similar disturbances have visited New England in the past but, from descriptions available, the hurricane of September 1815 appears to have been the only storm comparable in scope, intensity, and destructiveness. Thus 123 years have passed since the last hurricane of this magnitude and as many years may lapse before another. It is, however, entirely possible that a hurricane may occur in season at any time when meteorological conditions are similar to those of September 21.

Emergency Protection of Water Supplies. Water works officials and water department personnel in the flooded areas are to be highly commended for their ingenuity and faithful devotion to duty while working under trying conditions and the strain of long hours. The experiences of these men during the flood of 1936, when similar problems were encountered, was of great importance in carrying out the work during the recent catastrophies. The Department of Public Health was able to be of early assistance in connection with the public water supplies, as the Department had warning as early as Monday, September 19, of approaching flood conditions in certain of the streams. Telephone warnings to water officials were sent out on this day, and engineers were stationed in the various river valleys on the following day. The engineering district organization again proved its value, particularly in the western part of the state, which was practically cut off from the Boston Office by the rising flood waters of the easterly tributaries of the Connecticut River and the effects of the hurricane. Advices from the Western District Office indicated that the most serious problems were in that area and that more engineers were needed to cope with the situation. As it was impossible to reach this area by highway from Boston, the National Guard rendered invaluable service by transporting engineers and equipment by airplane from Boston to Springfield.

As a safeguard in protecting the public from any water-borne disease, boiling orders were issued in 33 municipalities supplied from public water supplies. These orders were in some cases issued by

the local authorities acting on their own initiative and in others on advice of the Department of Public Health. Chlorination again played a very important part in the rehabilitation of the affected supplies, and in this connection 27 chlorinating units were installed on various public water supplies. These units consisted of 18 hypochloride-devices, installed by the engineers of the Department, and 9 portable chlorine-gas machines that were installed with the assistance of the chlorination equipment companies. Commendation should be given for the prompt delivery of chlorinators to the affected areas when transportation facilities were seriously affected. Within four days, all public water supply systems in the state had been inspected and samples sent to the laboratory for analysis. Boiling orders were not removed on any of the affected supplies unless the water was being adequately chlorinated or the results of bacterial examination showed the water to be free from bacteria characteristic of pollution and safe for drinking without treatment. Of the public water supplies affected by the flood and hurricane, some 24 had disruptions to the distribution systems by the washing out of mains, which in several instances seriously depleted the storage in distribution reservoirs before the proper gates could be closed. In 14 cases, the sources of supply were flooded out, and it was necessary to rely on storage in distribution reservoirs until flood waters had receded, chlorination apparatus installed or pumping equipment reconditioned. There were about 10 cases of power failures in pumping stations or treatment plants, and in two municipalities standpipes were damaged by the hurricane. The water supplies of Ware, the Monson State Hospital at Monson, and East Brookfield were three of those most seriously affected.

The water supply of the town of Ware is taken from a dug well and group of tubular wells located adjacent to Muddy Brook, a tributary of the Ware River. The wells and pumping station were inundated by the flood waters, but in anticipation of such conditions the reservoir had been filled with several days' supply, and a chlorinator had been loaned by the Department of Public Health. When the flood waters had receded, the dug well was sterilized and pumped out, the emergency steam pumps prepared for use and the chlorinator installed. All water pumped into the distribution system was heavily chlorinated. The experience with this supply was almost an exact repetition of that during the flood of 1936.

At the Monson State Hospital, the water supply consists of a group of tubular wells located adjacent to the Quaboag River, and water is also furnished to the hospital from the supply of the town

of Monson. The Quaboag River flooded the wells and pumping station at the hospital, and the town of Monson was unable to supply water to the hospital because of difficulties with its own supply. To meet this emergency, a fire hose was laid on a railroad trestle across the river, and water was supplied from the distribution system of Palmer Fire District No. 1. When the town supply of Monson was rehabilitated, the use of this hose line was discontinued and water supplied from the town. When the flood waters had receded from around the hospital wells and pumping station, the pumping station equipment was overhauled, an emergency chlorinator installed and all water supplied from this source adequately chlorinated.

The water supply of the town of East Brookfield is obtained from a dug well located on the westerly shore of Lake Lashaway. The water is pumped into the distribution system, and the excess enters a standpipe located on a hill top about ¼ mile from the well. The dam at Doane's Pond in North Brookfield, located on a tributary of Lake Lashaway, was washed out, and the water level of the lake was raised some 9 ft. in a few hours, inundating the well and pumping station and washing out a water main with the highway near the outlet of the lake. Before this main could be shut off, the standpipe was drained and toppled over by the force of the hurricane, leaving the town without a water supply. To meet the emergency, water was transported into town by trucks from neighboring communities and adequately chlorinated under proper supervision before distribution. A pumping engine was obtained from the Boston Fire Department to serve as an emergency pumping unit until the electric motors could be dried out, as the pumping station was 100% electrical. The break in the main was repaired, the fire engine suction placed in the well and the water, after heavy chlorination, pumped into the mains. The top 30 ft. of the 50-ft. steel standpipe were cut away with acetylene torches, and the lower 20 ft. were restored to their original position and placed in service.

Damage from the tidal wave accompanying the hurricane was chiefly in the southeasterly section of the state, in the vicinity of Buzzards Bay and Mount Hope Bay, in the vicinity of the Taunton River and also on the island of Martha's Vineyard. This tidal wave reached elevations varying from 10 to 15 ft. above mean sea level when it piled up on the shallow shores and into small bays and harbors. The force of this wave caused complete devastation in certain areas, especially in Swansea, Dartmouth, Marion, Mattapoisett, Fairhaven, Westport and Wareham. However, in these places the public water

supplies were not damaged to any great extent. The work of the Department in these areas consisted chiefly in assisting the local authorities in examining private sources of water supply that were inundated and polluted by the tidal wave.

Lessons for the Future. The close occurrence of the two recent major floods and a hurricane clearly demonstrates the need of more adequately protecting public water supplies against such disasters. This becomes apparent when we note that the damage to certain water supply systems by the 1938 flood was identical with that by the 1936 flood. In several municipalities, in which the sources of water supply, pumping stations, and other structures were inundated during both the 1936 and 1938 floods, provision should be made for protecting them from the entrance of flood waters insofar as economically practicable. In this connection, consideration should be given to the construction of dikes or the water-proofing of structures to above flood level.

While not entirely within the province of water officials, it seems advisable that dams, culverts, bridges and similar structures on our waterways be examined to determine their stability under maximum flood conditions and that they be repaired or reconstructed if necessary.

Power failures were caused not only by flood waters but in a great many instances by the demolishment of power lines by the hurricane. The tendency in recent years has been to rely to a large extent on electrical power in pumping stations and treatment plants, and in some cases no auxiliary standby units with secondary power have been provided. While the hurricane demonstrated that the electrical power systems could be crippled for a period of several days, it is also apparent that even a severe sleet storm might cause such a failure. It is, therefore, essential to provide suitable auxiliary power units, other than electrical, in pumping stations and treatment plants to help prevent disruption to water service.

In many cases, mains and river crossings that were carried out in the 1936 flood were again washed away during the 1938 flood. The loss of river crossings and mains, in many instances, caused large sections of the distribution system to be without water. The lack of gate valves or their inaccessible location during flood conditions caused considerable wastage of water and in some instances seriously depleted the amount of water in storage. In replacing washed-out mains, they should be so installed as to prevent their dislodgement under flood conditions, and the necessary gates should be provided on the distribution system.

The damage to two standpipes is a reminder that such structures should be so designed that, even when empty, they will withstand a wind pressure of hurricane magnitude. Since standpipes are usually located on hill tops, it should be borne in mind that the wind velocities in such locations are considerably greater than those recorded by some of the official weather stations at lower elevations.

The experiences in 1936 taught us certain lessons that helped to a considerable extent in meeting similar conditions in 1938. The recent floods and hurricane should bring forcibly to mind the frequency with which such catastrophies can occur and that every practicable measure should be taken by water works officials to protect their water supplies from the effects of such disasters.

THE RESTORATION OF WATERSHED FORESTS IN THE HURRICANE AREA

BY A. C. CLINE*

[*Read February 16, 1939.*]

Despite the statement once made to me by a prominent engineer that his first choice of a cover for a certain watershed in New England would be a tin roof, I believe that for existing conditions of run-off in this region nothing ever will be found more satisfactory than a good cover of trees. Furthermore, I feel certain that many water supply boards envisage the eventual development of watershed forests that will be not merely covers to prevent soil erosion and to regulate run-off, but productive forests yielding annual harvests of wood products, creating gainful employment and providing an income to the community. At least, as a forester, I shall assume that such is an ultimate objective.

That this objective seems far removed at present is due in part to the character of the cover on many of our watersheds at the time of their acquisition: open or brush-covered land devoid of trees of desirable species and requiring nothing short of planting in order to establish a forest cover. If it were not for the present generally depleted condition of our forests, progress in forestry undoubtedly would be much more rapid, and our practices would center more around conservative cutting methods and less around planting.

In addition to the time element involved in starting with bare ground, planting has in many instances brought about a condition of artificiality: even-aged stands of uniform spacing, generally coniferous, and not infrequently composed of exotic species whose fitness for the particular site on which they are planted is largely a matter of chance. Such stands are especially subject to insect pests and diseases, and the expense of protecting them may be so great that all hope of profitable wood production is sooner or later abandoned. Such costly treatments as spraying, cutting off weeviled leaders and creosoting egg masses, together with the poor form and early decline of trees poorly adapted to the site, are a recurring source of discouragement to those who would have the watershed forest show a profit from the sale of wood products. I presume that so much plant-

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ing around reservoirs has contributed to some extent to the popular but false notion that forestry is largely planting; and evidently some forest managers are not above being influenced by the same well-intentioned propaganda that has popularized this apparently sure and simple way of starting a forest. For even in cases where young, natural stands of potentially good timber already are present on cutover lands I have observed a tendency to cut down the existing growth and replace it with planted conifers in pure stands.

And while I am mentioning some of the common practices in publicly-owned forests I should include the treatment to which many older stands of natural origin are subjected: a treatment for which I can think of no better term than "park-making," a process that takes the form of cutting all the seedling reproduction and sapling understory, in effect destroying the basis for a future crop, and increasing the exposure of the soil to the action of the elements. Perhaps such a practice is carried on for the purpose of fire protection, as in the case of pruning each and every tree in plantations, regardless of the size or shape of the individual tree or of the fact that scarcely more than one-tenth of the number of trees planted at the beginning should be carried through to the final stand. Or perhaps in some instances such drastic treatments are due to an oversupply of relief workers untrained in the more refined silvicultural practices and useful only in such jobs as cutting and piling brush and wholesale pruning.

But I suspect that another reason why these practices are so common today, especially on the smaller forests that cannot afford to employ a forester, is that few people untrained in the art of forest production appreciate the vitally important relation of the make-up of the forest, that is, the mixture of species, the spacing of the trees, and the variety of ages and sizes present, to its security against destructive agencies, its ease of maintenance and its economic outcome. A forest that is allowed to grow up naturally over a long period of time is a most complex community of plant and animal organisms, each individual of which contributes something to the whole and plays a part in creating a favorable environment for the continued life and reproduction of the community. In departing too far from a policy of working in harmony with Nature one may find himself confronted with the same sort of problems as those common to the production of other artificial crops. It is well to recall that only by means of poison sprays, fertilizers and painstaking care and cultivation is modern farm crop production possible. For instance, no one would think of growing apples without spraying several times each

season. But forest crops cannot stand these high costs of care and protection and still show a profit. You may remember my remarks on this point when addressing you on a previous occasion, on the subject of the control of the gypsy moth; more specifically, the statement that costly, recurring expenditures for spraying and creosoting destroyed all hope of showing a profit on wood crop production.

Of course, we must admit that back of the current extravagance in managing our publicly-owned forests in this part of New England lies the fact that most of us living in this section are not forestry-minded to begin with. We are fish and game-minded, park-minded, and recreation-minded, but all too frequently we have failed to gain an appreciation of the possibilities of forest management from the standpoint of producing wood products on an economic basis. There is no reason why watershed forests cannot fulfill all the needs for protection of the soil and regulation of run-off, provide a limited amount of recreational use, and at the same time yield annual or periodic cuts of timber and other products. Continuous production, or sustained annual yield, as it is known to foresters, is chiefly a matter of developing a forest growing-stock in which there is such a distribution of trees of all ages and sizes, from seedlings to mature trees, that a certain proportion of the growing stock reaches economic maturity and is ready for cutting every year, this proportion being equal to the annual growth on all the trees. It makes no difference whether the forest is large or small. By maintaining a proper distribution of ages, annual harvests may be carried on indefinitely, barring such catastrophies as hurricanes, of course.

Before coming to the specific recommendations for forest treatments in the hurricane area, I wish to refer once more to the desirability of dealing with the forest as a whole: a community of trees, shrubs, ground plants, animals, and microörganisms in the soil, all interrelated and mutually dependent, and not simply as rows of trees set out orchard-fashion in an open field. In this connection I should like to quote some advice given recently by the Committee on Silviculture of the New England Section, Society of American Foresters,[1] as follows: ". . . . the forester should at all times be guided insofar as possible by an understanding of the composition (species present) and ecological relations of the climax (virgin) forest for the particular locality in question. He should appreciate the character of the natural associations of plant organisms, and should follow natural tendencies unless he is reasonably sure that his information justifies

[1]Journal of Forestry, 37, 1, January, 1939.

departure therefrom. Cutting aimed at reproducing stands should give full consideration to natural site potentialities and tendencies. Plantings likewise should be based on creating conditions of maximum stability and security consistent with the objectives of ownership. Even though such deterioration may have taken place in the soil, as a result of farming, repeated clear cuttings or fires, as to make impossible the immediate reëstablishment of many of the valuable but exacting species which once occupied the site, we should plan on their gradual introduction as improved conditions of cover and soil permit." So you see in dealing with the task of forest restoration we should delve more deeply into the fundamentals of tree growth and not be content to base our accomplishments on the number of trees we have planted.

Not only do the so-called "natural" mixtures of tree species afford the greatest security against destructive agencies and the least costly maintenance, but a study recently conducted at the Harvard Forest by Goodell[2] indicates that the natural associations of trees are most effective in moderating run-off and streamflow. For example, for conditions of light winter snowfall, but heavy rains and cold weather, such as are characteristic of southern New England, the results of the study suggest that hardwoods, the most common natural cover in this part of the region, may be preferable to conifers. The reason for this is that the absence of a protective blanket of snow over the ground tends to permit the water-soaked soil to freeze deeply. The chief deterrent to such deep and long-continued freezing is full exposure to the sun's rays which, in the case of hardwood trees bare of leaves, are allowed to reach the ground with little hindrance. Furthermore, the warmth aids in early thawing of the soil in the spring, increasing its absorbtiveness at a time when heavy rains occur. In northern New England, on the other hand, where there is a heavy blanket of snow in the winter and generally a coniferous cover, the thick canopy of foliage tends to retard the melting of the snow in the spring, thus moderating run-off.

Needless to say, in citing these findings I have assumed that heavy spring floods are something to be avoided on all watersheds and that a more equable flow of water throughout the year is to be desired.

There is still another basic consideration that I should like to mention, and that is the form of forest which is best adapted to watersheds. I believe there is no doubt that the answer to most

[2]Goodell, B. C. A Study of Spring Flood Factors as Influenced by Forest Cover Types in Central New England. Unpublished Manuscript, 1937.

STAND A

Harvard Forest Photos.

STAND B

FIG. 1.—THE INFLUENCE OF DENSITY OF STOCKING ON THE FORM AND QUALITY OF THE STAND.

Both stands are the same age, but Stand A is densely stocked while Stand B is poorly stocked. The extreme crookedness of white pine when grown at wide spacings is due to attacks by the white pine weevil, an insect which kills the leader. The larger branches on the more open grown trees are due to the greater room available for lateral expansion of the crown. On open land white pine should be planted at a spacing not greater than 5 feet. With such a spacing weeviled trees are forced to straighten and branches die while still small.

forest management problems on watersheds lies in the all-aged or selection form, in which trees of all ages and sizes are growing together, either singly or in small groups. With a forest of this sort, clear cutting, with resultant exposure and drying out of the soil, increased fire hazard, and more rapid run-off, is avoided. Instead, under the selection method, cutting takes the form of the yearly or periodic removal of a relatively small number of the older trees, these trees being distributed throughout the stand rather than concentrated in one place. This form of forest provides the greatest possible protection of the site, for, with the exception of the small openings made in logging, the ground is completely covered at all times. The restriction of cuttings to single trees or small groups keeps fire hazard at a minimum; there is no need for resort to planting, since seed trees are abundant and seedlings become established naturally in any openings; aesthetic values are retained in the fullest degree; and the conditions of shade and moisture characteristic of an all-aged form of forest favor the more valuable, long-lived species of trees. These advantages seem to be particularly applicable to the smaller watershed forests near centers of population, where protection against fire and avoidance of unsightly cutting are of great importance. To be sure, time will be required to develop such forests, but if the objective of an all-aged form of forest is constantly kept in mind, all current treatments may be made to contribute towards that end and its attainment hastened. I wish to emphasize this point especially in view of the present tendency to plant even-aged stands, to cut the undergrowth of young trees in older stands, and to harvest by clear cutting, all of which result in even-aged rather than all-aged stands.

In the treatment of conditions as we find them after the hurricane there exists an excellent opportunity to adopt new and better practices, to bring about some reforms as it were and not merely to replace that which was blown down. In discussing post-hurricane practices I wish to deal first with the stands that were either completely destroyed or severely damaged and then with the young stands that escaped injury.

Stands of Middle Age or Older. In the case of older stands that were completely blown down, whether softwood or hardwood, or mixtures, the prompt salvage of the merchantable logs and cordwood, followed by the piling and burning of the slash, will serve to eliminate the fire hazard and to leave the ground in a favorable condition for natural regeneration of the forest. Although hardwood slash constitutes much less fire hazard than softwood slash, and, in any

case, decays within a few years, especially if in contact with the ground, I have assumed that on most of the smaller watershed forests it will be found possible and desirable to burn it. Otherwise, hardwood slash may be lopped and scattered to good advantage.

There is every reason for cleaning up the debris as soon as possible. Not only will the fire hazard continue for several years to come where no cutting or burning is done, but uncontrolled fires will destroy most of the young growth and thus greatly increase the cost of establishing a new stand. Furthermore, the down trees and slash will serve as breeding places for insects and fungi, some of which may be expected to attack any standing living trees.

During the process of slash disposal any hardwood saplings that have been badly damaged but still remain firmly rooted should be cut close to the ground. The remaining stumps will send up sprouts the first growing season after cutting, and many of them will be sufficiently straight and well-formed to make desirable timber trees. I should recommend the policy of cutting all spindling, bowed over, broken-topped, or otherwise injured small hardwood trees. There is almost no danger of killing the trees. Our New England hardwoods are noted for their sprouting ability.

In general, no planting will be necessary in cases of the complete blow down of old stands. The excellent crop of pine seed last fall should in many cases result in an unusually dense reproduction of pine, which will be supplemented on the heavier soils by an abundance of hardwoods. Not only is there a large amount of viable seed stored in the top layer of the soil, but thousands of small hardwood seedlings and saplings present beneath the older stands, even though broken or cut off, will sprout up again and make rapid growth under the new conditions. Cutover pine lots in particular are noted for the dense thicket of hardwoods that becomes established a few years after logging, except on the lightest and driest soils. The finest young hardwood stands in the Harvard Forest owe their origin to the clear cutting of pure pine stands. Much of the area of blow down may be treated the same as cutover land, which in this part of the country may be depended upon to restock itself naturally, provided destructive fires are prevented. In the past, much money was wasted in the needless planting of cutover land and, indeed, not a few of such plantations were so completely and quickly overgrown by the new volunteer stand that the plantations have since been abandoned, and properly so. In any event there should be no haste in deciding whether planting is necessary. Four or five years is not too long

to wait, particularly in the case of the more fertile soils or where seed trees are still standing.

On the light, sandy soils or on dry ridge tops, planting may be the only solution, but even here it will prove advantageous to allow a few years to pass, thus permitting what growth does come in, be it what it may, to shade the ground and afford some protection to the planted trees. In any case, it is unsafe to plant young conifers on cutover pine land until the third season following cutting, because of the Pales weevil, an insect that is attracted to fresh pine cuttings and feeds upon and kills coniferous seedlings. This same insect will destroy a portion of the natural pine seedlings resulting from last fall's seed, but enough will survive to form, along with the hardwoods, fairly well-stocked mixed stands.

The young mixed hardwood, or pine and hardwood stands, that we may expect to come in on areas of blow down will require little more than one or two weeding treatments during the first ten years in order to free the most desirable trees from overtopping inferior trees and to lay the foundation for a valuable timber crop. In selecting the species to be favored one should take into account the various factors of site and soil, susceptibility of the various species to insect pests and diseases, their influence upon one another when growing together in mixtures, and all that goes towards building up a safe, easily maintained stand of valuable trees.

In the case of older stands in which only part of the trees blew down, there is even less reason for resort to planting and greater assurance of a satisfactory restocking by natural means. Although bark beetles and exposure may kill some of the trees that thus far have escaped damage, in all probability enough will survive to act as sources of seed, the resulting seedlings supplementing those originating from seed stored in the duff. In any event, these older residual trees should be saved, if possible, not only for their seed but for the protection they afford the soil and the young trees. On the drier sites, the establishment of a satisfactory stocking of seedlings in the openings between the older trees may be promoted, where not too rocky, by scarifying the soil with the aid of a spike-toothed harrow, or some similar device for breaking up the leaf litter and duff and mixing them with the mineral soil. Frequently the results of such seed bed preparation exceed all expectations in the way of a dense catch of seedlings. Incidentally, you will doubtless observe during the next few years that in the depressions, where bare mineral soil has been exposed by the uprooting of the old trees, seedlings of certain

hardwood species have come in abundantly. The same will take place on the beds of charcoal where slash has been burned. In fact, a scarcity of natural reproduction is more likely to be due to an unfavorable condition of the seed bed rather than to a lack of seed.

On areas where the former stand was completely blown down, the ensuing stand will of course be even-aged, but where a part of the stand remains there is an excellent opportunity to make a start towards the development of the all-aged form of stand, which is so ideally suited to watershed purposes. Although the newly established generation will be essentially even-aged, the sprouts resulting from the cutting of bent over or broken saplings will forge ahead of all the seedlings thus forming what later will appear to be an intermediate age.

Young Coniferous Stands. Coniferous plantations, even though scarcely older than twenty years, proved highly susceptible to windthrow, and in many of them the trees now lie prostrate or sharply inclined like a field of grain flattened by a summer storm. The task of slash disposal is a difficult one, but there appears to be no better way than to lop off the branches and burn them, then cut the stems near the base, so that they will come in close contact with the ground and their decay thereby hastened.

Because of the lack of a seed source, natural regeneration cannot be expected. But in turning to a replanting of the area as the solution, there should be no hesitation in departing from earlier procedures. To the fullest extent possible, pure coniferous plantations should be replaced with mixtures of species having such habits of growth and requirements as to be mutually beneficial when growing together. Few indeed will the cases be where a marked improvement cannot be made in the composition, spacing or arrangement of the new stand. While a great many questions remain to be answered relative to the mixing of conifers under the various conditions of climate, topography and soil, and especially so in connection with the use of exotic species, it has been definitely established that pure stands are particularly and highly susceptible to both insects and diseases. Exceptions should be made, of course, in the case of native species occurring naturally in pure stands. I need not tell you that the majority of white pine plantations in this part of New England have been reduced to rows of bushes by the repeated killing of the leaders by the white pine weevil, or that red pine is now being attacked in Connecticut by the European pine shoot moth. In eastern Massachusetts red pine has been attacked more recently by an as yet unidentified sawfly that strips off the needles. There may be those among

Harvard Forest Photo.

FIG. 2.—THE ALL-AGE OR SELECTION FORM OF STAND IS IDEALLY SUITED TO WATERSHED PROTECTION

Cutting is restricted to individual trees or small groups, thus reducing fire hazard to a minimum; there is no need for resort to planting, since abundant seedling reproduction is naturally established in any openings; aesthetic values are retained to the fullest degree; and conditions of shade and moisture are favorable for tree growth and encourage the more valuable species of tree.

In the photograph the small opening in the foreground resulted from the cutting of a group of mature trees. This opening will soon be restocked with natural reproduction. Middle-aged groups of trees appear in the background.

you who already have been obliged to resort to spraying to control this newest pest. Yet such remedies as poison sprays are purely temporary. Within the next few years another spraying may be necessary in order to avoid serious damage.

Time does not permit discussion of the subject of pure *versus* mixed stands, or detailed recommendations for planting new stands in place of those blown down. Such decisions as are called for under the present circumstances fall within the province of silviculture, and I would suggest that you seek the advice of a competent specialist in this field. While many persons set about planting forest trees with seemingly as little concern as though planting cabbages or some other

annual crop, the fact of the matter is that the creation of a forest that will remain healthy and vigorous over a period of many decades and yield sound, valuable timber requires the utmost skill and foresight. Many plantations appear promising while still in the juvenile period, but this is no criterion of later vigor or long life.

Because hardwood plantations have seldom, if ever, proved successful on open land in this region, partly on account of frost damage during the seedling stage, I have referred only to conifers for use on areas of complete blow down. However, studies being currently undertaken at the Harvard Forest indicate that hardwoods may be successfully planted beneath the protective canopy of older coniferous stands, or in small openings made by cutting one or more trees, after the conifers have attained sufficient height. This may be a means, at some later date, of introducing certain hardwood species into coniferous stands to form a very desirable uneven-aged mixture, at the same time getting rid of poorly formed individual conifers that are not worth retaining as crop trees. Further research needs to be done before definite recommendations are possible.

Young Hardwood Stands. Just a few words regarding the young hardwood stands that survived the hurricane. And I presume you have noticed that, on the whole, hardwoods withstood the wind much better than conifers. There are thousands of acres of young hardwood stands in the formative period, on watersheds and elsewhere, that have originated on cut-over land and that a comparatively small outlay would put in satisfactory condition for profitable timber production. Generally, the possibilities of improving these young wild stands have in the past been completely overlooked. Through weedings and improvement cuttings, trees of inferior species, form or condition can be eliminated from the stand in favor of the more promising trees of the more desirable and valuable species. Here again I cannot hope to describe the technique employed in such silvicultural treatments, but I should like to say that anyone who enjoys working with stands of trees will obtain the greatest satisfaction in weeding young stands in the sapling stage. The work goes rapidly; one can see the marked change as he goes along, and within a few years he will witness the quick response that has been made by the better trees, once overtopping inferior trees are out of the way, and the generally improved appearance of the young stand. Weeding is the most needed and profitable treatment that can be applied today to the large area of cutover and naturally restocking wild land. The improvement of young volunteer stands should be a prominent part

STAND A

Harvard Forest Photos.

STAND B

FIG. 3.—On the better grades of soil excellent stands of hardwood may be developed simply through weeding the volunteer sapling growth on cutover areas. The object of weeding is the favoring and freeing of the most desirable future crop trees from over-topping inferior trees. The photograph of Stand A shows the first weeding being carried out in a young hardwood stand on cutover land. The workman is cutting a rank-growing sprout clump from a large stump in favor of well-formed seedlings of oak and ash. The photograph of Stand B shows how a properly weeded stand appears at 25 years of age. Only trees of desirable species, form and quality make up the main stand.

of any program of forestry in the region, regardless of the new problems introduced by the hurricane.

As a final thought may I suggest that in the general plan of forest restoration in the hurricane area a little more emphasis be placed on growing hardwoods, a little less on conifers. Though I am not inclined to be influenced in choice of species by the possibility of another hurricane, it is true that conifers are more subject to windthrow than are hardwoods. And certainly they are much more subject to complete destruction by fire during early life. But, more important than either of these considerations, I believe, is the fact that over the larger part of southern New England hardwoods are favored by Nature to a greater extent than conifers. By allowing ourselves to be guided by natural tendencies in the establishment of our new forests I believe we shall save a great deal of later trouble and expense, produce better forests, and best meet the needs of watershed protection.

Discussion

Roger W. Estey.* In one of the illustrations a hardwood growth contained a lot of large trees and some smaller ones. How should that be thinned out?

Mr. Cline. I should let the young trees take care of themselves for the time being and just pay attention to the better individuals among the older trees, to see that these have enough room for healthy, vigorous growth. It is a matter of having sufficient room for the expansion of the tree's crown. Crown expansion and growth in diameter of the bole go hand in hand. By thinning the stand, the rate of diameter growth is increased and thereby the time required to produce logs of a given size shortened. On the other hand, groups of young trees should be kept quite dense, since restricted room forces the tree to grow straight, kills the lower branches before they become large and hastens natural pruning.

A Member. I want to ask Mr. Cline if he can tell us the relative amount of water used by the different trees, because that might be important on watersheds, where the need is water rather than trees.

Mr. Cline. I am afraid I am not prepared to give you any figures on the relative evaporation rate of the different species. Of course, it is much greater in the case of hardwoods than conifers. You all know that conifers will grow on dry, sandy soils, whereas many of the hardwoods require rich, moist soils. But I think to answer your question fully one needs to consider the month by month run-off

*Superintendent, Danvers, Mass.

throughout the year as influenced by all the factors of soil and cover, and not merely the rate of transpiration. There is a great deal of difference between the soils found under conifers and those under hardwoods as regards permeability, water-holding capacity, depth of freezing, and other characteristics which determine in some degree what portion of the total precipitation will find its way into the reservoir. Much more research is needed before this question can be satisfactorily answered.

A Member. We have several stands of pine in several stages of growth from last year's setting-out to fifteen years of age. When is the proper time to start pruning?

Mr. Cline. I do not know just what your objective is in pruning but, leaving out of consideration that of fire protection, the time to start pruning is when the trees are about 3 to 5 in. in diameter and around 15 to 18 ft. in height, the reason being that the smaller the knotty core in the center the larger the surrounding cylinder of clear wood. And in the case of white pine there is an excellent reason for waiting until the trees are log high. Due to attack by white pine weevil many trees are ruined by forks and crooks. If you prune too early, you may waste time pruning trees that you later find are so severely damaged by weeviling as to be worthless. So in the case of white pine it is always well to hold off pruning until the trees are at least 12 ft. high—until you can tell what the butt log is going to be. I am speaking from the standpoint of producing high-quality lumber, at least in the butt log, and not protecting the plantation from fire. There is a great deal of wholesale pruning in watershed forests, and I must say it is a rather painful sight to foresters to see so much money spent in pruning trees, when we know that no more than from one-sixth to one-tenth of those trees should end up in the final stand. It seems that you have wasted a lot of money pruning trees which will never reach maturity.

A Member. What is your idea of the best way to thin trees, to girdle or to cut?

Mr. Cline. In a plantation?

The Member. Yes.

Mr. Cline. I should say that in coniferous plantations on most watersheds the undesirable trees should be cut. A girdled conifer will dry out and remain standing for many years, constituting quite a fire hazard as well as being unsightly. There is nothing wrong with girdling, as such, as a means of reducing congestion in the stand, but I think from the standpoint of fire protection you will be much better

pleased to have these trees cut and laid close to the ground, where they will decay.

Mr. Estey. You have spoken from a forestry proposition. Looking at it from a water-works angle what effect would different cover have on the color of the water?

Mr. Cline. I am not prepared to answer that question. I presume you are thinking that hardwoods discolor the water.

I have worked in regions like the Appalachians and the Ozarks where the forests are very largely hardwood, and I have never noticed any discolored water in the streams. I believe that water flowing through hardwood forests growing on upland soil, not swamp, would not be discolored. I know when water comes out of a red maple swamp, or any swamp, it will be discolored, but I think that where it is flowing under upland hardwoods the water will be as clear as though the cover were conifers. I may be mistaken, but that is what I should say.

In closing I might say that the President's reference to Mr. Frank E. Winsor's death reminds me of a most pleasant acquaintance with him and other members of the Metropolitan Commission over a number of years, and especially since the Quabbin Reservoir has been under construction. There is one point I tried to make with these gentlemen in connection with their planting, and that was the desirability of close spacing. Instead of planting 6 or 7 ft. apart, which means a slow closing in of the stand, coarse branches, and poor lumber, I suggested that they close the spacing to approximately 5 ft. This means more trees per acre, but there is much more profit in it, as far as the final timber stand is concerned, than with these wider spacings.

ERRATUM

Economic Design of Hydraulic Fill Dam Sections, by Harry H. Hatch, published in Vol. 52, September, 1938, p. 364.

A number of equations should be revised as follows:

(1) $P=\frac{1}{2}wh^2/\sin A$

(2) $P_h=\frac{1}{2}wh^2$

(3) $P_v=\frac{1}{2}wh^2\cot A$

(6) $$F=C\left(\frac{w'}{w}\frac{b}{h}-\cot A\right)$$

(7) $$b=h\frac{w}{w'}\left(\frac{F}{C}+\cot A\right)$$

(9) $$b+o=h\frac{w}{w'}\left(\frac{F}{C}+\cot A\right)+h\cot A$$

(11) $$S=\frac{w}{w'}\left(\frac{F}{C}+\cot A\right)+\cot A$$

(12) $$F=C\left(\frac{b}{h}-\cot A\right)$$ from (6) when $w=w'$

(13) $$\frac{b}{h}=\cot A+\frac{1}{C}$$

(14) $$S=2\cot A+\frac{1}{C}$$

when F=1 and w=w'; or equilibrium formulas for b and S

(18) $b=h\cot A+h^{1.05}$

(19) $S=2\cot A+h^{0.05}$

(20) Cancelled, as there is no need for it. Originally it was derived from (13), but an examination of revised (13) will show that the larger the angle A and the larger the value of C, the smaller becomes b for a given h.

Due to these corrections, Figures 3, 4, 5 and 6 are cancelled along with their text scattered on pages 372 and 374. The revised Figures and their text will be different. For instance, the lines in Figures 5 and 6 will be straight as can be seen from their revised equations (14) and (13), respectively, and not curved as given originally. For smaller angles A, the graphs of the revised equations (18) and (19) will be flatter than those given originally; but for larger angles, say for a core slope of 10 on 1, the old and revised equations will plot as in Figures 3 and 4, on pages 370 and 371, respectively.

PROCEEDINGS

MARCH 1939 MEETING

Hotel Statler, Boston, Mass.
Thursday, March 16, 1939.

President George A. Sampson in the chair.

Secretary GIFFORD announced the election of the following new members:

Patrick S. Nugent, Superintendent, Water Works, Lawrence, Mass.; Roger W. Moran, Superintendent, Water Department, Willimantic, Conn.; Walter A. Peirce, Manager, Water Department, Racine, Wisconsin.

ARTHUR C. KING discussed legislation pending in Massachusetts and Connecticut.

On motion of Harold L. Brigham, duly seconded, it was VOTED that the President be empowered to appoint a nominating committee in conformity with the constitution.

A paper, "Safeguards for Ground Water Supplies," was read by Leslie K. Sherman, Assistant Sanitary Engineer, Connecticut State Department of Health, Hartford, Conn.

A paper, "Pollution of Private Well Supplies," was read by Ernest J. Sullivan, Sanitary Engineer, Massachusetts Department of Public Health, Boston, Mass.

A paper, "Pollution of an Industrial Ground Water Supply by Organic Waste Products," prepared by Gordon M. Fair, Professor of Sanitary Engineering, Harvard Graduate School of Engineering, was read by Professor Edward W. Moore.

E. Sherman Chase gave a talk on the responsibility of water purveyors for the quality of water furnished, especially in the light of the recent court decision in the North Attleboro case, and also a recent English case.

William W. Brush, Harold L. Brigham, Frank L. Gifford, Linn H. Enslow, Arthur C. King, and Ralph M. Palmer took part in the discussion.

APRIL 1939 MEETING

Willimantic and Storrs, Connecticut
Thursday, April 27, 1939

The luncheon and afternoon meeting were held in the main dining-room of Connecticut State College.

President George A. Sampson in the chair.

Secretary GIFFORD. New members elected today are as follows:

Junior Member: John S. Bethel, Jr., Chemist, Filtration Plant, Lawrence, Mass.

Members: Ivan A. Buchanan, Engineer, Hayden, Harding and Buchanan, Boston, Mass.; John L. Hayden, Engineer, Boston, Mass.; Thomas James Rinaldo, Junior Sanitary Engineer, Metropolitan District Commission, Framingham, Mass.; Albert J. LePage, Senior Engineer, Metropolitan District Commission, Framingham, Mass.

The Association was welcomed to Willimantic by Harry J. Kaufman, Chairman of Willimantic Water Committee, and to Connecticut State College by Dr. P. R. Bramwell.

A paper, "Willimantic's New Filtration Plant," was read by Roland F. Kittredge, Superintendent of Filtration. John F. Collins, City Engineer of Willimantic, opened the discussion. Roger W. Esty asked some questions regarding the plant.

A paper, "Points of Contact between Town Water and Fire Departments," was read by Percy C. Charnock, Manager, Municipal Protection Department, New England Insurance Exchange, Boston, Mass.

A paper, "Maintenance of Water Works Equipment," was read by Sherman L. Rogers, District Engineer, Water Bureau, Metropolitan District of Hartford County. This was illustrated by lantern slides.

MAY 1939 MEETING

Manchester Country Club, Manchester, N. H.

Thursday, May 25, 1939.

President George A. Sampson in the chair.

Secretary GIFFORD announced the election of the following new members at the Executive Committee meeting:

Frank Neiduski, Water Superintendent, Clerk and Registrar, Dudley, Mass.; Albert Henry Fournier, Water Commission Clerk, Lewiston, Me.; A. V. Garabedian, Consulting Engineer with Hayden, Harding & Buchanan, Boston, Mass.

The Association was welcomed to Manchester by Honorable Dr. Damase Caron, Mayor of Manchester, Member of Water Board.

A paper "Some Public Misconceptions Concerning the Function, Value and Significance of Water Analysis," prepared by Charles D. Howard, Director, Division of Sanitation, N. H. State Board of Health, was read by Leonard W. Trager. E. Sherman Chase, Samuel

M. Ellsworth, Francis H. Kingsbury, Gordon M. Fair, and Robert Spurr Weston took part in the discussion.

A paper, "Comparison between the 1916 and 1938 Specifications for Gate Valves," was read by Samuel E. Killam, Director and Chief Engineer, Water Division, Metropolitan District Commission, Boston, Mass. Reeves J. Newsom, Samuel M. Ellsworth, and E. Sherman Chase participated in the discussion.

A paper, "improvement in Power and Pumping Facilities of the Manchester Water Works," was read by P. A. Shaw, Superintendent and Engineer, Manchester Water Works. Percy R. Sanders, Francis H. Kingsbury, Robert Spurr Weston, E. Sherman Chase, Theodore Cate and J. Hastings Howland took part in the discussion.

BOOK REVIEWS

THE FLOW OF HOMOGENEOUS FLUIDS THROUGH POROUS MEDIA. By *Morris Muskat*. International Series in Physics, McGraw-Hill Book Company, New York, N. Y., 1937. Cloth, 6x9 in., xix and 763 pp., illus., diagrs., $8.00.

This book should delight mathematicians who will discover therein a new mine that has been opened up for the application of the mathematical sciences. Upon closer examination they will also realize that a good deal of such mining has been done by the author himself who proves to be an excellent mathematician.

The first impression that a civil engineer would derive from glancing over the pages of this book, might not be so favorable. The practicing engineer will be discouraged too easily by the extensive use of mathematical tools which are beyond his understanding. This is unfortunate, because this book does contain valuable contributions which could be utilized to advantage in problems of seepage and ground water flow in relation to engineering structures.

A large portion of this book deals with problems of flow as they are met with in the field of oil production. The reviewer is not prepared to discuss these parts of Dr. Muskat's book which undoubtedly represent an outstanding contribution to the oil industry. It is the intention of this discussion to review the book purely from the viewpoint of the civil engineer.

The main emphasis throughout the entire book is placed on rigorous (or as nearly rigorous as possible) mathematical solutions of a large variety of problems relating to seepage and ground water movement. The author has collected in this one volume most of the important contributions in this field that have been published over a period of many years in several languages and in widely scattered periodicals. In addition he has added much original material and innumerable critical and stimulating remarks. It is the type of book that specialists in this field and research workers will appreciate most. To the average reader, for whom the contents of this book must be bewildering, the excellent summaries found at the end of every chapter should prove very helpful.

One reason why a fairly good knowledge of the subject is a prerequisite to reading this book is the frequent references to material that

appears in later chapters. While it is, of course, not always possible to present extensive material without having to interrupt the line of thought occasionally, one cannot help but feel at times that the elements of which this book is composed could be organized differently before their assembly, so that the reader need not hunt for essential information before proceeding with the study of the book. Chapter II, on Darcy's law, particularly can be criticized from this standpoint. Only a reader who is thoroughly familiar with this subject matter will read it with profit. To others it will be rather confusing.

Dr. Muskat presents the viewpoint of the physicist whose desire it is to express the resistance of a fluid to flow through a porous medium by a true constant. To this end he proposes the introduction of a new unit which he has named the "darcy" in honor of the French engineer who formulated the law that is generally known as Darcy's law. This new unit is related to the "coefficient of permeability" that has been commonly used in the field of civil engineering, somewhat like "grams" are related to dynes. Just as engineers adhere in most of their calculations to the use of weights rather than mass, it appears to the reviewer that the exceedingly simple and practical method of measuring the coefficient of permeability in cm. per sec. will inevitably continue to be used by civil engineers in their investigations of flow of water through soils in relation to engineering problems. On the other hand there is no doubt that for scientific studies of the flow of various types of fluids through porous media there is a need for an absolute coefficient of permeability such as is proposed by Dr. Muskat.

The book contains a thorough discussion of the experimental methods for determining the coefficient of permeability. The writer is in full agreement with Dr. Muskat in his statement that direct permeability tests are much simpler and more accurate than any attempt to determine the permeability indirectly from the grain size distribution of the soil. It is surprising how much research is concentrated on futile attempts in this direction. Allen Hazen is often referred to as the founder of such methods. This is true, but at the same time one must not forget that Allen Hazen developed this method only for filter sands and other relatively uniform, clean, granular materials. In speaking of soils containing clayey particles he said: "Estimates of seepage of water through such materials based on mechanical analysis are usually not of much value" (1).*

The chapter on Darcy's law contains tables summarizing the permeability tests on oil sands conducted by different investigators. In

*Figures in parentheses refer to the bibliography.

this connection it would be well to refer also to the tests by F. H. Newell (1885) on Bradford oil rocks which were conducted with water, kerosene, and crude oil. An apparatus which is essentially the same as that used by later investigators was employed. These tests are discussed in detail by F. H. King in his elaborate treatise to which Dr. Muskat refers in several places in his book.

It is interesting to note that the fundamental equation governing the flow of compressible liquids is identical with the general differential equation of the consolidation of fine-grained soils which was derived by Terzaghi in 1923, (2) and (3). While the problem of compressible liquids does not concern the civil engineer, the problem of consolidation of soils is of primary importance in the entire field of earth work and foundation engineering. Also, the large supply of water that can be made available from artesian sources, is frequently due to compression, that is decrease in void space, of the ground water carrier due to the increasing pressure of the overburden. This increase in pressure is simply due to the decrease in buoyancy resulting from the gradual drop in artesian pressure.

Another problem of ground water flow that is of importance in foundation engineering is the non-steady flow toward wells obtained in the temporary lowering of ground water for construction purposes. Dr. Muskat states: "The extension of the Dupuit-Forchheimer theory which has been frequently used to treat such problems, involves so many questionable assumptions that reproductions of the analyses based on this theory hardly seem to be warranted, even though nothing better has yet appeared". Unfortunately, engineers cannot wait with their construction until a rigorous solution to this problem has been obtained. The reviewer believes that the approximate solutions offered by H. Weber (4) give reasonably accurate results.

In connection with such problems we should not overlook the fact, that an approximate solution based on assumptions that reflect closely the actual conditions is of much greater value in engineering than a rigorous mathematical solution that is based on simplifying assumptions of questionable character. It is true that at present we do not know the magnitude of the errors introduced in the approximate solutions of the non-steady state of flow toward wells. However, in somewhat similar problems of non-steady flow through soils (3) approximate solutions have been found to yield results that agree remarkably well with the rigorous solution. It is inconceivable that we should eliminate approximate solutions from engineering. For over fifty years Forchheimer's approximate solutions of the flow of ground water

toward wells have served the engineers well and they have hardly been bettered by a rigorous approach from an engineering point of view. Therefore, the writer regrets that Dr. Muskat takes such a critical attitude toward Forchheimer's contributions and even neglects to mention that he originated the graphical method for plotting flow nets, or analyzing multiple well systems. One should not forget that the men who first visualize a problem correctly but offer only an approximate mathematical solution have contributed more toward the advancement of their fields, than those who in due time, after additional mathematical tools have been developed, succeed in replacing the approximate solutions by more rigorous solutions.

The rigorous solutions of seepage beneath sheet pile walls and dams contained in this book deserve careful study by those who deal with such problems. The equations, also, lend themselves to the computation of the velocity distribution along the discharge face, which is of importance in connection with studies of safety against piping. It would enhance the value of this book to the civil engineer if in a future edition special attention were paid to this question.

In connection with the problem of seepage beneath a sheet pile wall, the numerical results of the computations are very interesting. It is shown that even if as little as a few per cent of the pervious stratum is not closed, the amount of seepage will not be reduced appreciably. While it is evident that in driving a cut-off wall through a pervious sand stratum into an impervious clay stratum one will always drive the sheet piles well into the clay, it is inevitable that in certain types of pervious soils the sheet pile wall will suffer seriously during driving. It is not uncommon that entire sheets are split open or curled up and the total open space may amount to several per cent of the total area. From the numerical data presented by Dr. Muskat one must conclude that a badly damaged sheet pile wall has little value in reducing the seepage losses. However, in many cases the purpose of a sheet pile wall is, principally, to reduce the seepage pressures at the downstream side of a dam or cofferdam and thereby increase its safety against piping. In such cases a sheet-pile wall that does not penetrate to an impervious stratum, may well serve its purpose.

This review would become too lengthy if the writer should attempt to present a comprehensive discussion of the wealth of material that Dr. Muskat has assembled in this book. It is an invaluable reference work for all who possess more than an elementary knowledge of the problems of seepage and ground water movement in relation to engineering structures.

ARTHUR CASAGRANDE

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(4) H. Weber, Die Reichweite von Grundwasserabsenkungen mittels Rohrbrunnen, Berlin 1928.
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THE WATER SUPPLY OF THE COUNTY OF LONDON FROM UNDERGROUND SOURCES. *By Steven Buchan.* Memoirs of the Geological Survey of Great Britain. His Majesty's Stationery Office, London, England, 1938; British Library of Information, 50 Rockefeller Plaza, New York, N. Y. Cloth, 6x9¾ in., vi and 260 pp.; illus., diagrs., $1.75.

The County of London covers an area of 74,850 acres and includes a population of about four and one half million. The public water supply is furnished by the Metropolitan Water Board which serves also an additional three and one half mililon people. The average daily per capita water consumption is 44 U. S. gallons. Most of this water comes from surface sources in the higher reaches of the Thames and Lea, but the Metropolitan Water Board is estimated to extract in excess of one half gal. per capita daily from underground sources, while an additional five and one half gal. per capita daily appears to be drawn privately from the ground.

In the first part of this Memoir the geological formations from which ground water is derived are described. The second part contains the record of 1,080 wells.

GORDON M. FAIR